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Growth Effects of Major Land Use Projects: Volume II. Compilation of Land Use Based Emission Factors

Abcor, Inc.

Prepared For
Environmental Protection Agency

June 1976

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GROWTH EFFECTS OF MAJOR LAND USE PROJECTS: VOLUME II - COMPILATION OF LAND USE BASED EMISSION FACTORS

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16. ABSTRACT

Growth Effects of Major Land Use Projects is a research program whose goal is to formulate a methodology to predict air pollutant emissions resulting from the construction and operation of two types of major land use projects, large residential projects and large concentrations of employment (i.e., office parks and industrial parks) Emissions are quantified from the major project, from land use induced by the major project, from secondary activity occurring off-site (ie., generation of electricity by utilities), and from motor vehicle traffic associated with both the major project and its induced land uses.

This report documents the development of a set of land use based emission factors (i.e., emissions per unit of building floor area or per dwelling unit) that are used to estimate emissions from the induced land uses and secondary activities. To accomplish this energy consumption in several categories of buildings is quantified.

Previous and subsequent reports (i.e., Volume I and Volume III) document the development of a model to predict the induced land use, a methodology for predicting vehicular traffic, and the estimation of emissions from vehicular traffic.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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VOLUME II - COMPILATION OF LAND USE BASED EMISSION FACTORS

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ABBREVIATIONS

A	Ash percentage in fuel by weight
apt.	apartment
Btu	British thermal unit
cl.d.d.	cooling degree day, Fahrenheit
cl.d.d.°K	cooling degree day, Kelvin
cu.ft.	cubic foot
d.d.	degree day (either heating or cooling), Fahrenheit
d.u.	dwelling unit
ht.d.d.	heating degree day, Fahrenheit
ht.d.d.°K	heating degree day, Kelvin
J	Joule
kg	kilogram
kWh	kilowatt-hour
lb.	pound
M	thousand
m^2	square meter
op.hr.	operating hour
S	sulfur percentage in fuel, by weight
SIC	Standard Industrial Classification
sq.ft.	square foot (floor area)
yr.	year
PM	Particulate Matter
SO_x	Sulfur Oxides
CO	Carbon Monoxide
HC	Hydrocarbons
NO_x	Nitrogen Oxides

GLOSSARY OF SELECTED DEFINITIONS ENERGY CONVERSIONS

1 British Thermal Unit (BTU) = heat required to raise the temperature of one pound of water by 1°F.

1 Therm = 100,000 BTU

1 Kilowatt-hour (kWh) = 3,412 BTU

1 ton of refrigeration = 12,000 BTU per hour

heating degree days = 65° F minus average daily temperature, when average daily temperature is below 65°F.

cooling degree days = 65°F minus average daily temperature, when average daily temperature is below 65°F.

average daily temperature = (daily high temperature + daily low temperature) ÷ 2

ENGLISH - SI CONVERSIONS

1 Degree-day°F = 5/9 Degree day°C

1 British Thermal Unit = 1055.06 joules (J)

1 Kilowatt-hour = $3.6*10^6$ joules

1 Therm = $1.0551*10^8$ joules

1 ton of refrigeration = $3.5169*10^3$ watts (W)

1 British Thermal Unit/hour = $2.9308*10^{-1}$ watts

I. INTRODUCTION AND APPROACH

A. INTRODUCTION

This report documents the results of the fifth and sixth phases of a study of the Growth Effects of Major Land Use Projects (GEMLUP). The principal objectives of the GEMLUP study are to formulate a methodology to predict air pollutant emissions from:

- Two types of major land use developments: large concentrations of employment such as office or industrial parks and large residential developments
- Secondary land development that is induced by the two types of major land use development projects
- Motor vehicular traffic associated with both the major project and secondary development.

GEMLUP relates to a number of EPA programs, including air quality maintenance plan (AQMP) development [1], environmental impact statement (EIS) review [2], the indefinitely suspended portions of indirect source review [3], and the prevention of significant air quality deterioration, or nondegradation [4]. Explicit or implicit in these programs is an evaluation of air quality impacts of land use plans or project developments. GEMLUP is designed to formulate and test a method of evaluating land use impacts at the project scale, and, in the process, develop a set of land use based emission factors potentially useful at the regional scale.

The study was divided into six phases:

Phase 1 - Specification of a preliminary model and generation of a list of data requirements

Phase 2 - Data collection

Phase 3 - Causal analysis of the land use model using path analysis

Phase 4 - Development of predictive equations for the land use model and development of a traffic model

Phase 5 - Development of indices of fuel consumption

Phase 6 - Translation of fuel consumption indices into land use based emission factors.

This volume of the final report concerns itself with phases 5 and 6, i.e., the development of indices of fuel consumption in buildings and the translation of those indices into land use based emission factors.

There are two additional volumes of the final report. Volume I discusses phase 1, phase 2, and phase 3. Volume III contains the results of phase 4, a summary of Volumes I and II, and a documentation of the application of the models.

B. ORGANIZATION OF THE REPORT

The remainder of this introductory chapter discusses the general approach to development of land use based emission factors. The following chapter is a compilation of the land use based emission factors generated in this study. Chapter III discusses in the development of energy consumption indices for each building type. Chapter IV discusses the generation of the land use based emission factors from these activity factors.

C. APPROACH TO LAND USE BASED EMISSION FACTORS

The objective of this phase of the GEMLUP study was to develop a set of land use based emission factors to permit the estimation of air pollutant emissions resulting from the construction and operation of a major land use project. These emission sources may be principally categorized as follows:

- Stationary source emissions occurring on the site of the major project (e.g., the on-site combustion of fuel oil for space heating needs)
- Stationary source emissions occurring at the land use induced by the major project (e.g., the on-site combustion of fuel oil for space heating needs)
- Secondary (i.e., occurring off-site) stationary source emissions (e.g., the combustion of fuel oil at the local electric utility to serve the electricity demand of the major project and induced land uses)
- Mobile source emissions (e.g., emissions due to motor vehicular traffic generated by the major project and induced land uses).

The latter category, mobile sources, is treated separately in Volume III of this report.

The estimation of emissions from the first three categories, all stationary sources, is the subject of this volume of the report. The means of this estimation is the use of land use based emission factors, that is, emissions per unit area of a particular land use category. Given the size of the major project and the amount of land use, air pollutant emissions may then be estimated by taking the product of the appropriate land use based emission factor and the area of a particular land use.

Previous compilations of land use based emission factors [5,6] have treated emissions as a function of land area, viz.,

$$\text{emission factor} = \frac{\text{emissions}}{\text{unit land area}}$$

For example, in the Hackensack Meadowlands Study [5], this was an appropriate approach as the emission factors were developed for a specific region with a specified density of development. However, the requirements of the GEMLUP study necessitate the development of emission factors that are more generalizable. In particular, the emission factors presented in this report are a function of building floor area, viz.,

$$\text{emission factor} = \frac{\text{emissions}}{\text{unit building floor area}}$$

As the output of the land use model in this project is in units of building floor area, the question of the density of development is moot. It should be noted that a true land use based emission factor may be constructed for a particular application by taking the product of the factor presented here and an appropriate floor area ratio (FAR), viz.,

$$\frac{\text{emissions}}{\text{unit land area}} = \frac{\text{emissions}}{\text{unit floor area}} * \text{FAR}$$

where FAR is the floor area ratio or building floor area per unit lot area. In regional studies, an adjustment may be necessary between the net FAR and gross FAR (i.e., including streets, vacant land).

1. Emission Factor Structure

The land use based emission factors and emissions per unit floor area may be disaggregated into two factors, an activity factor (i.e., fuel throughput, etc., per unit floor area), and the "Standard" emission factor (i.e., emissions per unit fuel). For example, in the case of fuel oil space heating consumption, this would be,

$$\frac{\text{emissions, gr.}}{\text{floor area, } 10^3 \text{ sq.ft.}} = \frac{\text{oil consumption, gals.}}{\text{floor area, } 10^3 \text{ sq.ft.}} * \frac{\text{emissions, gr.}}{\text{oil consumption, gals.}}$$

Given this structure, a complete set of land use based emission factors would consist of an n-dimensional array with specific values given for a pollutant species, fuel or process type, building category, and, in some cases, energy requirements (e.g., region of the country).

Ignoring the solvent evaporation, solid waste disposal, and other miscellaneous emissions*, the energy consumption related emission factor can be generalized as follows:

$$\frac{\text{emissions}_{i,j,k}}{\text{sq.ft.} \cdot \text{year}} = \Big[\Big(\frac{\text{Btu}_i}{\text{sq.ft.} \cdot \text{year}} + \frac{\text{Btu}_i}{\text{sq.ft.} \cdot \text{ht.d.d.}} + \frac{\text{Btu}_i}{\text{sq.ft.} \cdot \text{cl.d.d.}}\Big) * \frac{1}{\text{heat content}_i} * \frac{1}{\text{seasonal efficiency}_i} * \frac{\text{emissions}_j}{\text{unit fuel}_i}\Big]_k$$

where

ht.d.d. = heating degree days per year

cl.d.d. = cooling degree days per year

and for a particular fuel type i, pollutant species j and building category k.

---

*Emissions from these sources are not considered in this report, since there is both more limited information about their characteristics and that they may be expected to display more variation in per unit floor area emissions between parts of the country. However, the emission factor structure discussed above is amenable to their inclusion. It is recommended that they be included in areas where there are significant emission sources and/or better information concerning their characteristics is available.

The fourth term in this equation, emissions per unit fuel, are the commonly used values determined directly from the EPA Compilation of Air Pollutant Emission Factors [7]. Hence, the focus of this project is generating the first three terms (i.e., the activity factor).

The first three terms identify the fuel consumption per building floor area given the heating and cooling degree days. The heat content of a fuel in British thermal units is approximately constant and is well known [8]. It does display some variation for every fuel, especially for natural gas in different regions of the country [9].

The values for the efficiency for various building types and fuels are less well known. Efficiency can be defined in a variety of ways. The purpose of this application is to account for the differences in the amount of energy consumed by a building depending on the fuel type selected to provide that energy. This is not the heating unit efficiency, which is measured at a full load steady state operation. Thus, it does not account for rapid on and off cycling associated with the typical oversized furnace. Nor (in the case of gas furnaces) does it measure the pilot light fuel consumption when the furnace is off.

The desired efficiency measure is the ratio of heat loss from a structure to the energy input to the structure variously defined as efficiency of utilization or seasonal efficiency. Even with agreement on a definition of efficiency, there is some disagreement in the literature over what are appropriate values.

The term in brackets, the energy requirement per square foot and per square foot degree day, represents the energy requirements of a building. It is divided into three components:

- Process use of energy that is not related to climate; examples include:
  - Lighting
  - Elevators
  - Refrigeration
  - Water heating equipment
  - Cooking equipment
  - Ventilation

- Energy requirements for space heating as a function of heating degree days*
- Energy requirements for air conditioning as a function of cooling degree days.

D. VARIANCE OF ENERGY REQUIREMENT, EFFICIENCY, AND EMISSION FACTORS

The energy requirement factor, the efficiency of utilization, and the standard emission factors are all estimates of the mean of population values and can be expected to display a large variation. In general, these factors are not precise indicators of energy requirement, efficiency, or emissions of a single source. They are more valid when applied to a large number of sources. Sources of variation in the energy requirement and efficiency factors are discussed below.

1. Energy Requirements

The expression of the energy requirement of a building category as solely a function of floor area and heating or cooling degree days is only a gross approximation of energy demand. While this approach was once used as a technique for predicting energy consumption for space heating in buildings [29], it is more typical now to use a calculated heat loss method [14]. The use of a degree day-square foot method is less precise in that it does not allow for variation in exposure, type of construction, ratio of exposed area to floor area, type of occupancy, outside temperature, wind, and humidity. In fact, recent research has shown considerable variation in

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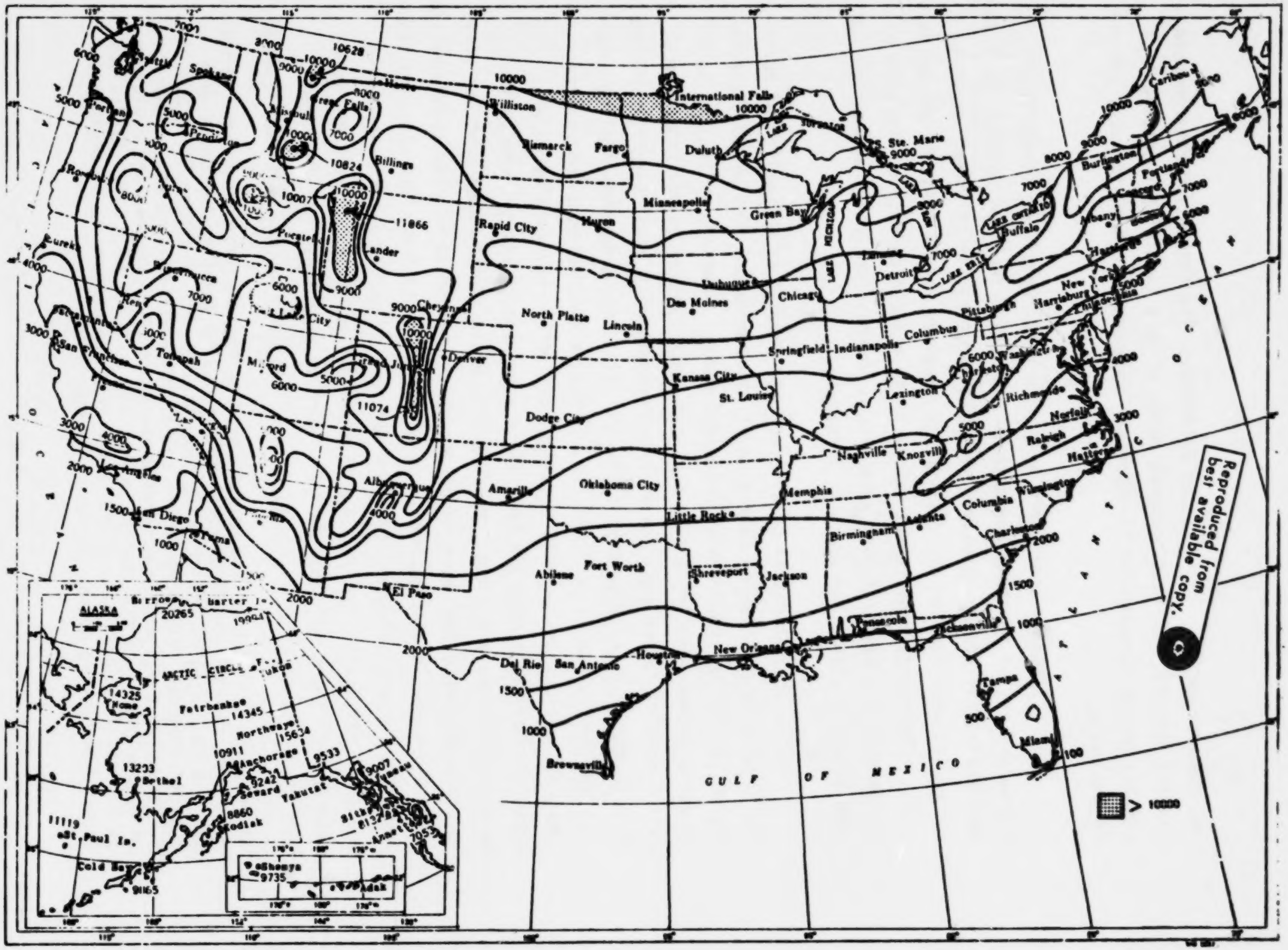
*Early this century heating engineers developed the concept of heating degree days as a useful index of heating fuel requirements. They found that when the daily mean temperature is lower than 65 degrees, most buildings require heat to maintain an inside temperature of 70 degrees. The daily mean temperature is obtained by adding together the maximum and minimum temperature reported for the day and dividing the total by two. Each degree of mean temperature below 65 is counted as one heating degree day. Thus, if the maximum temperature is 70 degrees and the minimum 52 degrees, four heating degree days would be produced. (70 + 52 = 122; 122 divided by 2 = 61; 65 - 61 = 4). If the daily mean temperature is 65 degrees or higher, the heating degree day total is zero. A map of iso-heating degree days for the United States is shown on Figure 1-1 [10].

Figure 1-1: NORMAL SEASONAL HEATING DEGREE DAYS (BASE 65°F) 1941–1970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2000
1500
1000
500
100
ALASKA
Barrow
20265
Barter Is.
19994
ARCTIC CIRCLE
Fort Yukon
Nome
14325
Fairbanks
14345
Northway
15634
Bethel
13203
Anchorage
10911
Seward
9242
Yakutat
9533
Juneau
9007
Sitka
8137
Annette
7053
Kodiak
8860
St. Paul Is.
11119
Cold Bay
9165
Shemya
9735
Adak
▨ > 10000

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the fuel consumption of identical buildings. The Center for Environmental Studies has observed that occupant behavior is a significant component of monthly energy consumption in identical townhouses in a residential project in New Jersey [11].

The only area where an energy requirement per square foot degree day factor has been adequate in predicting fuel consumption is in the residential oil dealer industry. In this industry, it is common practice to predict when another oil delivery is required on the basis of degree days alone. The energy requirement factor is in essence calculated for each oil customer on the basis of past experience, thereby implicitly accounting for type of construction and occupant lifestyle.

The estimation of cooling requirements as a function of building floor area and cooling degree days* poses problems similar to the estimation of heating requirements discussed above. However, unlike the relationship between heating degree days and space heating energy consumption, (viz., heating degree days can at least successfully predict energy consumption in the same building over time) the relationship between cooling degree days and energy use is less precise. There is considerable controversy among meteorologists, as well as air conditioning engineers as to what meteorological variables are most closely related to energy consumption by air conditioning systems. Many experts argue that because high humidity levels make people feel more uncomfortable as temperatures rise, some measure of moisture should be included in calculating energy needs for air conditioning. The Temperature-Humidity Index has been suggested as an alternative basis for calculating cooling degree days. In addition to humidity, some experts feel there are other factors, such as cloudiness and wind speed, that should be included in computation of energy needs for air conditioning.

---

*The cooling degree day is a mirror image of the heating degree day. After obtaining the daily mean temperature, by adding together the day's high and low temperatures and dividing the total by two, the base 65 is subtracted from the resulting figure to determine the cooling degree day total. For example, a day with a maximum temperature of 82 degrees and a minimum of 60 would produce six cooling degree days. (82 + 60 = 142; 142 divided by 2 = 71; 71 - 65 = 6). If the daily mean temperature is 65 degrees or lower, the cooling degree day total is zero [10].

Also, solar heat gain will vary between different regions of the country as the solar angle changes due to differences in latitude.

Nevertheless, this study will use cooling degree days as an index of cooling demand in nonresidential buildings. It is the most adequate index that is readily available for all areas of the country and for time periods shorter than a calendar year. A map of the United States showing iso-cooling degree days is shown in Figure 1-2.

For residential buildings, this study will use the estimated compressor operating hours of residential air conditioning units as compiled by Oak Ridge National Laboratory. It is a more adequate index than cooling degree days as it does take humidity and latitude into account. It is not used in this study for nonresidential buildings because it was developed for application to residential buildings only. In addition, regression analysis* of nonresidential building energy consumption showed no difference between the explanatory power of cooling degree days and compressor operating hours. A map of iso-compressor operating hours is shown in Figure 1-3. Their derivation is discussed in Appendix A.

2. Efficiency of Utilization

For reasons similar to the above, the efficiency of utilization will also display variation between buildings of the same category. The type and size of the heating system and age and condition will effect its efficiency. In particular, in residential applications, the size of the furnace relative to the structure's heat loss will determine the number of times it is cycling on and off, thereby not operating at full load steady state and maximum efficiency. Losses are incurred during the system start up and shut down as well as when the system is off due to flue heat loss and, in gas systems, pilot light consumption.

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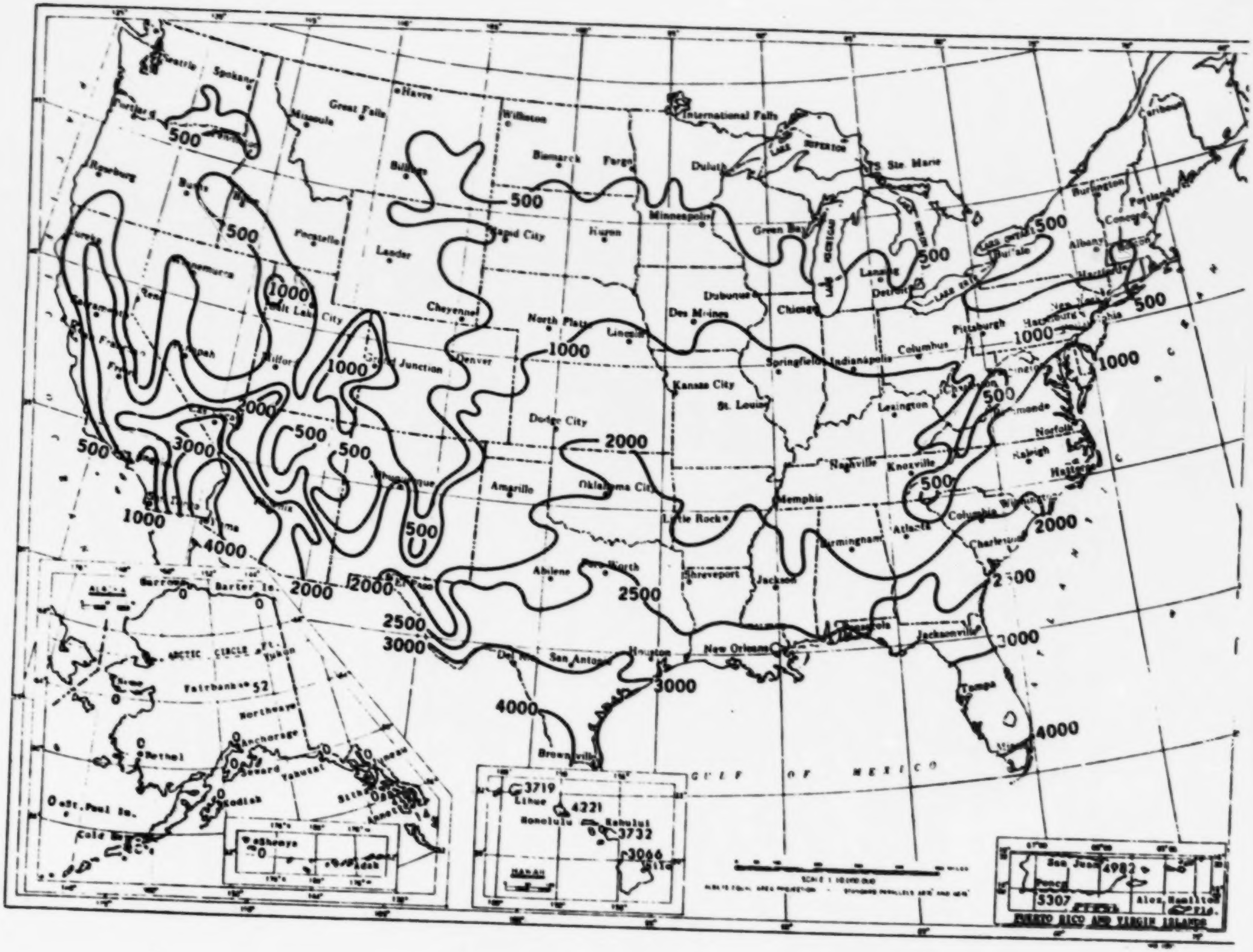
*See Appendix B and C.


500
1000
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Seattle
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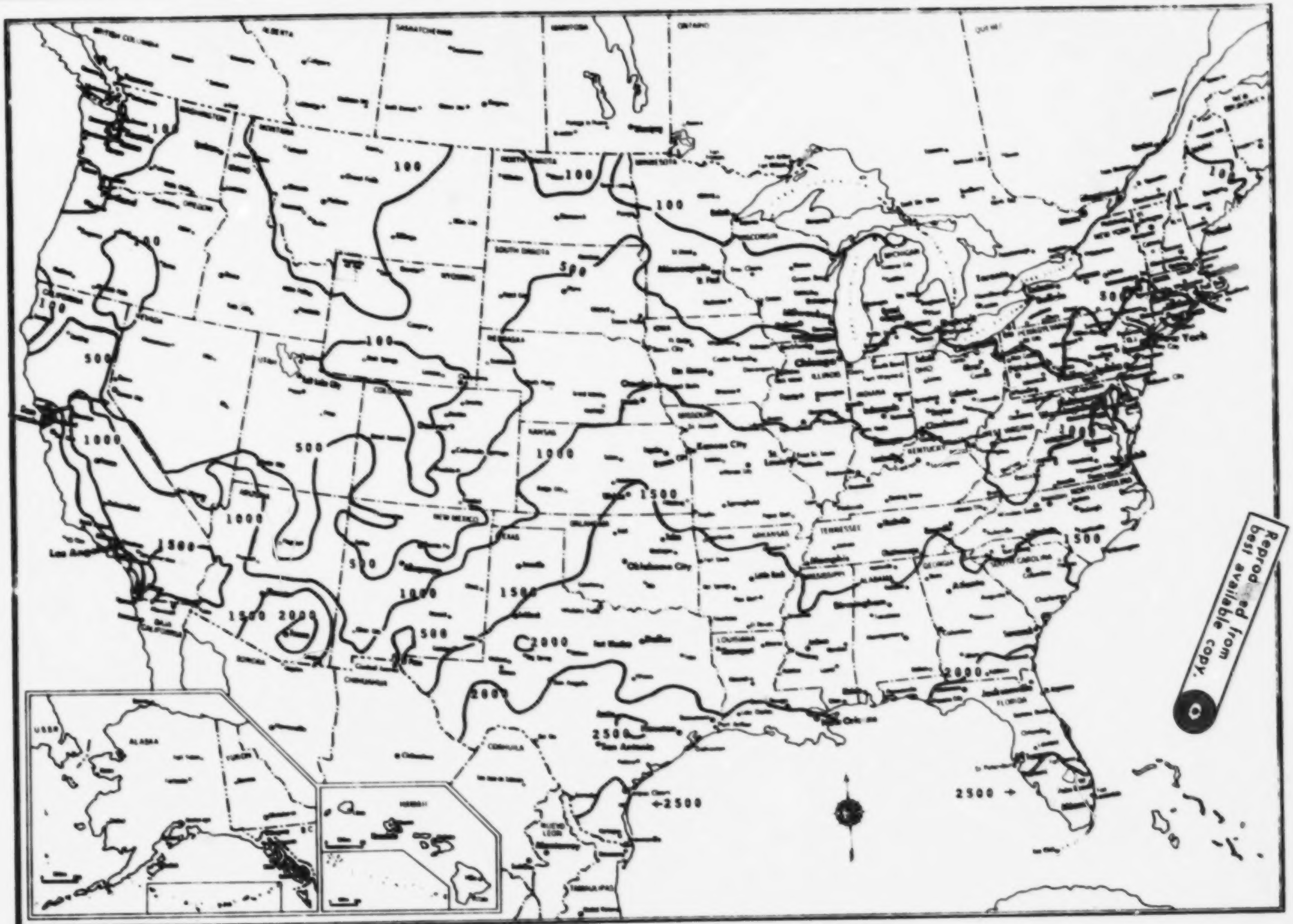
Portland
Roseburg
Boise
Eureka
Winnemucca
Reno
Sacramento
San Francisco
Fresno
Tonopah
Ely
Pocatello
Salt Lake City
Milford
Las Vegas
Phoenix
Yuma
Havre
Great Falls
Missoula
Billings
Lander
Cheyenne
Grand Junction
Denver
Albuquerque
El Paso
Williston
Bismarck
Fargo
Rapid City
Huron
North Platte
Lincoln
Dodge City
Amarillo
Oklahoma City
Abilene
Fort Worth
Del Rio
San Antonio
Houston
Brownsville
International Falls
Duluth
Minneapolis
Des Moines
Dubuque
Kansas City
St. Louis
Little Rock
Shreveport
Memphis
Jackson
New Orleans
Sault Ste Marie
Green Bay
Chicago
Springfield
Indianapolis
Lansing
Detroit
Columbus
Lexington
Nashville
Knoxville
Birmingham
Atlanta
Pensacola
Jacksonville
Tampa
Charleston
Columbia
Wilmington
Raleigh
Norfolk
Hatteras
Richmond
Pittsburgh
Harrisburg
Philadelphia
New York
Buffalo
Albany
Hartford
Boston
Burlington
Concord
Portland
Caribou
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
GULF OF MEXICO
ALASKA
Barrow
Barter Is.
ARCTIC CIRCLE
Ft. Yukon
Fairbanks
52
Northway
Nome
Bethel
Anchorage
Seward
Yakutat
Juneau
Sitka
Annette
St. Paul Is.
Kodiak
Cold Bay
Shemya
Adak
0
HAWAII
Lihue
3719
Honolulu
4221
Kahului
3732
Hilo
3066
San Juan
4982
Ponce
5307
Alex. Hamilton Fld.
PUERTO RICO AND VIRGIN ISLANDS

Figure 1-2: NORMAL SEASONAL COOLING DEGREE DAYS (BASE 65°F) 1941-1970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NEW MEXICO
TEXAS
KANSAS
SOUTH DAKOTA
Oklahoma City
Kansas City
San Antonio
Los Angeles
New Orleans
ALASKA
HAWAII
COAHUILA
NUEVO LEON
FLORIDA
GEORGIA
SOUTH CAROLINA
NORTH CAROLINA
ILLINOIS
MICHIGAN
USSR

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FIGURE 1-3. ANNUAL AIR CONDITIONER COMPRESSOR-OPERATING HOURS FOR HOMES THAT ARE NOT NATURALLY VENTILATED. Source: Oak Ridge National Laboratory [17].

II. SUMMARY OF LAND USE BASED EMISSION FACTORS

This chapter presents a tabular summary of the land use based emission factors as developed in Chapters III and IV. The emission factors are presented in units of pounds of pollutant emitted per "measure" for oil and gas combustion. For electricity consumption, the factors are in terms of kilowatt-hours per "measure". The measure, depending on the activity involved, may be per square foot of building floor area, per square foot heating degree day, per dwelling unit, etc.

The quantity of secondary, i.e., offsite, emissions occurring due to electricity consumption depends on the nature of the local electric utility generating station. It is suggested that the local utility be contacted to determine the appropriate emission factor. Default values of pounds of pollutant emissions per kilowatt-hour sold are presented in Table 2-1 and are based on data in References 7, 34, and 35. It should also be pointed out that the emissions due to increased electrical demand do not necessarily occur at the nearest generating plant.

Tables 2-2 through 2-13 present the land use based emission factors for residential, commercial, institutional and industrial land uses. The industrial factors do not include process emissions, as explained in Chapter III.

Table 2-1 presents the default electric utility emission factors in SI (Système International d'Unités) units, kilograms of emissions per joule of electricity. Tables 2-14 through 2-25 presents the land use based emission factors in SI units.

The emission factors in the following tables are for uncontrolled emissions as presented in sections 1.1, 1.3, and 1.4 of AP-42 [7].

TABLE 2-1

TYPICAL EMISSION FACTORS FOR ELECTRIC UTILITIES

Pounds of pollutant emissions per kilowatt hour sold to customer

	PM	SO_x	CO	HC	NO_x
coal	$5.23 \times 10^{-3}A$	$1.53 \times 10^{-2}S$	4.03×10^{-4}	1.21×10^{-4}	2.21×10^{-2}
oil	6.34×10^{-4}	$1.26 \times 10^{-2}S$	2.38×10^{-4}	1.58×10^{-4}	8.32×10^{-3}
gas	1.19×10^{-4}	7.13×10^{-6}	2.02×10^{-4}	1.19×10^{-5}	8.32×10^{-3}

Kilograms of pollutant emissions per joule sold to customer (SI Units)

	PM	SO_x	CO	HC	NO_x
coal	6.59×10^{-10}	$1.93 \times 10^{-9}S$	5.08×10^{-11}	1.52×10^{-11}	2.78×10^{-9}
oil	7.99×10^{-11}	$1.59 \times 10^{-9}S$	3.00×10^{-11}	1.99×10^{-11}	1.05×10^{-9}
gas	1.50×10^{-11}	8.98×10^{-13}	2.55×10^{-11}	1.50×10^{-12}	1.05×10^{-9}

Note: A 33.3% overall plant efficiency is assumed for coal fired plants [34].
A 31.6% overall plant efficiency is assumed for oil and gas fired plants [34].

A 10% transmission loss is assumed [35].

'S' and 'A' represent, respectively, the sulfur and ash percentage of fuel by weight.

TABLE 2-2

SINGLE FAMILY RESIDENTIAL LAND USE BASED EMISSION FACTORS

	pound of pollutant (or kilowatt-hours) per measure						
	PM	SO_x	CO	HC	NO_x	kWh	Measure
Space Heating							
Electricity	-	-	-	-	-	3.8	dwelling unit•ht.d.d.
Gas	2.6×10^{-4}	1.5×10^{-5}	5.1×10^{-4}	2.0×10^{-4}	2.6×10^{-3}	-	dwelling unit•ht.d.d.
Oil	2.2×10^{-3}	$3.2 \times 10^{-2}S$	1.1×10^{-3}	6.6×10^{-4}	2.6×10^{-3}	-	dwelling unit•ht.d.d.
Air Conditioning							
Central							
Electricity	-	-	-	-	-	4.7	dwelling unit•op.hr.
Gas	1.8×10^{-4}	1.1×10^{-5}	3.5×10^{-4}	1.4×10^{-4}	1.8×10^{-3}	-	dwelling unit•op.hr.
Room							
Electricity	-	-	-	-	-	5.1×10^{-1}	a.c. unit•operating hour
Process							
Hot Water							
Electricity	-	-	-	-	-	$1.4 \times 10^{+4}$	dwelling unit•year
Gas	3.0×10^{-1}	1.8×10^{-2}	6.0×10^{-1}	2.4×10^{-1}	3.0	-	dwelling unit•year
Oil	2.5	$3.7 \times 10^{-1}S$	1.2	7.5×10^{-1}	3.0	-	dwelling unit•year
Cooking							
Electricity	-		-	-	-	$3.5 \times 10^{+3}$	dwelling unit•year
Gas	1.1×10^{-1}	6.6×10^{-3}	2.2×10^{-1}	8.8×10^{-2}	1.1		dwelling unit•year
Miscellaneous	-	-	-	-	-	$7.9 \times 10^{+3}$	dwelling unit•year

Note: A 1600 square foot dwelling unit is assumed.
'S' represents the sulfur percentage of oil, by weight.

TABLE 2- 3

MOBILE HOME RESIDENTIAL LAND USE BASED EMISSION FACTORS

	pound of pollutant (or kilowatt-hours) per measure						
Activity	PM	SO_x	CO	HC	NO_x	kWh	Measure
Space Heating							
Electricity	-	-	-	-	-	2.32	dwelling unit·ht.d.d.
Gas	1.7×10^{-4}	9.9×10^{-6}	3.3×10^{-4}	1.3×10^{-4}	1.7×10^{-3}	-	dwelling unit·ht.d.d.
Oil	1.4×10^{-3}	$2.0 \times 10^{-2}S$	6.9×10^{-4}	4.2×10^{-4}	1.7×10^{-3}	-	dwelling unit·ht.d.d.
Air Conditioning							
Central							
Electricity	-	-	-	-	-	3.4	dwelling unit·op.hr.
Room							
Electricity	-	-	-	-	-	5.1×10^{-1}	a.c. unit·op.hr.
Process							
Hot Water							
Electricity	-	-	-	-	-	$1.3 \times 10^{+4}$	dwelling unit·year
Gas	3.0×10^{-1}	1.8×10^{-2}	6.0×10^{-1}	2.4×10^{-1}	3.0	-	dwelling unit·year
Oil	2.5	$3.6 \times 10^{+1}S$	1.2	7.5×10^{-1}	3.0	-	dwelling unit·year
Cooking							
Electricity	-	-	-	-	-	$3.5 \times 10^{+3}$	dwelling unit·year
Gas	1.1×10^{-1}	6.6×10^{-3}	2.2×10^{-1}	8.8×10^{-2}	1.1	-	dwelling unit·year
Miscellaneous	-	-	-	-	-	$7.9 \times 10^{+3}$	dwelling unit·year

Note: A 720 square feet per dwelling unit is assumed.
'S' represents the sulfur percentage of oil, by weight.

TABLE 2-4

LOW RISE MULTIFAMILY RESIDENTIAL LAND USE BASED EMISSION FACTORS

	pound of pollutant (kilowatt-hours) per measure						
Activity	PM	SO_x	CO	HC	NO_x	kWh	Measure
Space Heating							
Electricity	-	-	-	-	-	1.3	dwelling unit•ht.d.d.
Gas	1.2×10^{-4}	7.3×10^{-6}	2.4×10^{-4}	9.7×10^{-5}	1.2×10^{-3}	-	dwelling unit•ht.d.d.
Oil	1.1×10^{-3}	$1.7 \times 10^{-2}S$	5.7×10^{-4}	3.4×10^{-4}	1.4×10^{-3}	-	dwelling unit•ht.d.d.
Air Conditioning							
Central							
Electricity	-	-	-	-	-	1.5	dwelling unit•op.hr.
Gas	6.2×10^{-5}	3.7×10^{-6}	1.2×10^{-4}	5.0×10^{-5}	6.2×10^{-4}	-	dwelling unit•op.hr.
Oil	4.5×10^{-4}	6.4×10^{-3}	2.2×10^{-4}	1.3×10^{-4}	5.3×10^{-4}	-	dwelling unit•op.hr.
Room							
Electricity	-		-	-	-	5.1×10^{-1}	a.c. unit•op.hr.
Process							
Hot Water							
Electricity	-	-	-	-	-	$1.1 \times 10^{+4}$	dwelling unit•year
Gas	2.4×10^{-1}	1.4×10^{-2}	4.8×10^{-1}	1.9×10^{-1}	2.4	-	dwelling unit•year
Oil	2.0	$2.9 \times 10^{+1}S$	1.0	6.0×10^{-1}	2.4	-	dwelling unit•year
Cooking & Dryer							
Electricity	-	-	-	-	-	$3.8 \times 10^{+3}$	dwelling unit•year
Gas	1.2×10^{-1}	7.2×10^{-3}	2.4×10^{-1}	9.6×10^{-2}	1.2	-	dwelling unit•year
Miscellaneous	-	-	-	-	-	$4.4 \times 10^{+3}$	dwelling unit•year

Note: A 900 square foot dwelling unit is assumed.
'S' represents the sulfur percentage of oil, by weight.

TABLE 2-5

HIGH RISF MULTIFAMILY RESIDENTIAL LAND USE BASED EMISSION FACTORS

	pound of pollutant (or kilowatt-hours) per measure						
Activity	PM	SO_x	CO	HC	NO_x	kWh	Measure
Space Heating							
Electricity	-	-	-	-	-	1.5	dwelling unit·ht.d.d.
Gas	1.0×10^{-4}	6.2×10^{-6}	2.1×10^{-4}	8.3×10^{-5}	1.0×10^{-3}	-	dwelling unit·ht.d.d.
Oil	1.0×10^{-3}	$1.5 \times 10^{-2}S$	5.2×10^{-4}	3.1×10^{-4}	1.3×10^{-3}	-	dwelling unit·ht.d.d.
Air Conditioning							
Central							
Electricity	-	-	-	-	-	1.5	dwelling unit·op.hr.
Room							
Electricity	-	-	-	-	-	.51	dwelling unit·op.hr.
Process							
Hot Water							
Electricity	-	-	-	-	-	$6.2 \times 10^{+3}$	dwelling unit·year
Gas	1.4×10^{-1}	8.4×10^{-3}	2.8×10^{-1}	1.1×10^{-1}	1.4	-	dwelling unit·year
Oil	1.1	$1.6 \times 10^{+1}S$	5.7×10^{-1}	3.4×10^{-1}	1.4	-	dwelling unit·year
Cooking & Dryer							
Electricity	-		-	-	-	$3.8 \times 10^{+3}$	dwelling unit·year
Gas	1.2×10^{-1}	7.2×10^{-3}	2.4×10^{-1}	9.6×10^{-2}	1.2	-	dwelling unit·year
Miscellaneous	-	-	-	-	-	$5.9 \times 10^{+3}$	dwelling unit·year

Note: A 900 square foot dwelling unit is assumed.

'S' represents the sulfur percentage of oil, by weight.

TABLE 2-6

RETAIL ESTABLISHMENTS, WAREHOUSES, WHOLESALING ESTABLISHMENTS, LAND USE BASED EMISSION FACTORS

Activity	pound of pollutant (or kilowatt-hours) per measure PM	SO_x	CO	HC	NO_x	kWh	Measure
Space Heating							
Electricity	-	-	-	-	-	1.3×10^{-3}	sq.ft.· ht.d.d.
Gas	9.8×10^{-8}	5.9×10^{-9}	2.0×10^{-7}	7.8×10^{-8}	9.8×10^{-7}	-	sq.ft.·ht.d.d.
Oil	1.7×10^{-6}	$1.2 \times 10^{-5}S$	2.9×10^{-7}	3.3×10^{-5}	4.4×10^{-6}	-	sq.ft.·ht.d.d.
Air Conditioning							
Electricity	-	-	-	-	-	5.2×10^{-3}	sq.ft.·cl.d.d.
Process							
Hot Water							
Electricity	-	-	-	-	-	5.0×10^{-1}	sq.ft.·year
Gas	2.4×10^{-5}	1.4×10^{-6}	4.8×10^{-5}	1.9×10^{-5}	2.4×10^{-4}	-	sq.ft.·year
Oil	5.2×10^{-4}	$3.6 \times 10^{-3}S$	9.1×10^{-5}	1.0×10^{-2}	1.4×10^{-3}	-	sq.ft.·year
Lighting	-	-	-	-	-	8.0	sq.ft.·year
Auxiliary Equipment	-	-	-	-	-	3.6	sq.ft.·year
Appliances	-	-	-	-	-	2.0	sq.ft.·year
Refrigeration	-	-	-	-	-	8.9	sq.ft.·year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 2-7

OFFICE BUILDING LAND USE BASED EMISSION FACTORS

	pound of pollutant (or kilowatt-hours) per measure						
Activity	PM	SO_x	CO	HC	NO_x	kWh	Measure
Space Heating							
Electricity	-	-	-	-	-	1.9×10^{-3}	sq.ft.•ht.d.d.
Gas	9.4×10^{-8}	5.6×10^{-9}	1.9×10^{-7}	7.5×10^{-8}	9.4×10^{-7}	-	sq.ft.•ht.d.d.
Oil	1.7×10^{-6}	$1.2 \times 10^{-5}S$	2.9×10^{-7}	3.3×10^{-5}	4.4×10^{-6}	-	sq.ft.•ht.d.d.
Air Conditioning							
Electricity	-	-	-	-	-	1.5×10^{-3}	sq.ft.•cl.d.d.
Gas	7.4×10^{-8}	4.4×10^{-9}	1.5×10^{-7}	5.9×10^{-8}	7.4×10^{-7}	-	sq.ft.•cl.d.d.
Oil	1.3×10^{-6}	$9.1 \times 10^{-6}S$	2.3×10^{-7}	2.6×10^{-5}	3.4×10^{-6}	-	sq.ft.•cl.d.d.
Process	-	-	-	-	-	$2.8 \times 10^{+1}$	sq.ft.•year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 2-8

NONHOUSEKEEPING* RESIDENTIAL LAND USE BASED EMISSION FACTORS

Activity	pound of pollutant (or kilowatt-hours) per measure						Measure
	PM	SO_x	CO	HC	NO_x	kWh	
Space Heating							
Electricity	-	-	-	-	-	1.7×10^{-3}	sq.ft.•ht.d.d.
Gas	9.4×10^{-8}	5.6×10^{-9}	1.9×10^{-7}	7.5×10^{-8}	9.4×10^{-7}	-	sq.ft.•ht.d.d.
Oil	1.4×10^{-6}	$9.9 \times 10^{-6}S$	2.5×10^{-7}	2.8×10^{-5}	2.8×10^{-5}	-	sq.ft.•ht.d.d.
Air Conditioning							
Electricity	-	-	-	-	-	4.7×10^{-4}	sq.ft.•cl.d.d.
Gas	2.3×10^{-8}	1.4×10^{-9}	4.6×10^{-8}	1.8×10^{-8}	2.3×10^{-7}	-	sq.ft.•cl.d.d.
Oil	4.1×10^{-7}	$2.8 \times 10^{-6}S$	7.1×10^{-8}	8.0×10^{-6}	1.1×10^{-6}	-	sq.ft.•cl.d.d.
Process	-	-	-	-	-	$1.2 \times 10^{+1}$	sq.ft.•year

* Hotels, Motels, Dormatories, etc.

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 2-9

HOSPITAL LAND USE BASED EMISSION FACTORS

Activity	pound of pollutant (or kilowatt-hours) per measure						Measure
	PM	SO_x	CO	HC	NO_x	kWh	
Space Heating							
Electricity	-	-	-	-	-	2.2×10^{-3}	sq.ft.•ht.d.d.
Gas	1.8×10^{-7}	1.1×10^{-8}	3.7×10^{-7}	1.5×10^{-7}	1.8×10^{-6}	-	sq.ft.•ht.d.d.
Oil	3.3×10^{-6}	$2.3 \times 10^{-5}S$	5.8×10^{-7}	6.6×10^{-5}	8.7×10^{-6}	-	sq.ft.•ht.d.d.
Air Conditioning							
Electricity	-	-	-	-	-	5.9×10^{-3}	sq.ft.•cl.d.d.
Process							
Lighting	-	-	-	-	-	$1.5 \times 10^{+1}$	sq.ft•year
Auxiliary Equipment	-	-	-	-	-	$1.7 \times 10^{+1}$	sq.ft•year
Appliances	-	-	-	-	-	5.9	sq.ft.•year
Hot Water							
Electricity	-	-	-	-	-	5.0	sq.ft.•year
Gas	2.4×10^{-4}	1.4×10^{-5}	4.8×10^{-4}	1.9×10^{-4}	2.4×10^{-3}	-	sq.ft.•year
Oil	5.2×10^{-3}	$3.6 \times 10^{-2}S$	9.1×10^{-4}	1.0×10^{-1}	1.4×10^{-2}	-	sq.ft.•year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 2-10

CULTURAL BUILDING LAND USE BASED EMISSION FACTORS

Activity	PM	pound of pollutant (or kilowatt-hours) per measure				kWh	Measure
		SO_x	CO	HC	NO_x		
Space Heating							
Electricity	-	-	-	-	-	1.8×10^{-3}	sq.ft.·ht.d.d.
Gas	9.0×10^{-8}	5.4×10^{-9}	1.8×10^{-7}	7.2×10^{-8}	9.0×10^{-7}	-	sq.ft.·ht.d.d.
Oil	1.6×10^{-6}	$1.1 \times 10^{-5}S$	2.8×10^{-7}	3.2×10^{-5}	4.2×10^{-6}	-	sq.ft.·ht.d.d.
Air Conditioning							
Electricity	-	-	-	-	-	5.9×10^{-4}	sq.ft.·cl.d.d.
Gas	2.9×10^{-8}	1.7×10^{-9}	5.7×10^{-8}	2.3×10^{-8}	2.9×10^{-7}	-	sq.ft.·cl.d.d.
Oil	5.1×10^{-7}	$3.6 \times 10^{-6}S$	8.9×10^{-8}	1.0×10^{-5}	1.3×10^{-6}	-	sq.ft.·cl.d.d.
Process	-	-	-	-	-	$1.2 \times 10^{+1}$	sq.ft.·year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 2-11

CHURCH BUILDING LAND USE BASED EMISSION FACTORS

	pound of pollutant (or kilowatt-hours) per measure						
Activity	PM	SO_x	CO	HC	NO_x	kWh	Measure
Space Heating							
Electricity	-	-	-	-	-	2.9×10^{-3}	sq.ft.·ht.d.d.
Gas	1.4×10^{-7}	8.6×10^{-9}	2.9×10^{-7}	1.1×10^{-7}	1.4×10^{-6}	-	sq.ft.·ht.d.d.
Oil	2.6×10^{-6}	$1.8 \times 10^{-5}S$	4.5×10^{-7}	5.0×10^{-5}	6.7×10^{-6}	-	sq.ft.·ht.d.d.
Air Conditioning							
Electricity	-	-	-	-	-	3.8×10^{-3}	sq.ft.·cl.d.d.
Gas	1.8×10^{-7}	1.1×10^{-8}	3.7×10^{-7}	1.5×10^{-7}	1.8×10^{-6}	-	sq.ft.·cl.d.d.
Oil	3.3×10^{-6}	$2.3 \times 10^{-5}S$	5.7×10^{-7}	6.4×10^{-5}	8.6×10^{-6}	-	sq.ft.·cl.d.d.
Process	-	-	-	-	-	4.2	sq.ft.·year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 2-12

SCHOOL BUILDING LAND USE BASED EMISSION FACTORS

Activity	pound of pollutant (or kilowatt-hours) per measure						
	PM	SO_x	CO	HC	NO_x	kWh	Measure
Space Heating							
Electricity	-	-	-	-	-	1.7×10^{-3}	sq.ft.• ht.d.d.
Gas	8.0×10^{-8}	4.8×10^{-9}	1.6×10^{-7}	6.4×10^{-8}	8.0×10^{-7}	-	sq.ft.• ht.d.d.
Oil	1.2×10^{-6}	8.5×10^{-6}	2.1×10^{-7}	2.4×10^{-5}	3.2×10^{-6}	-	sq.ft.• ht.d.d.
Air Conditioning							
Electricity	-	-	-	-	-	4.7×10^{-4}	sq.ft.• cl.d.d.
Gas	2.3×10^{-8}	1.4×10^{-9}	4.6×10^{-8}	1.8×10^{-8}	2.3×10^{-7}	-	sq.ft.• cl.d.d.
Oil	4.1×10^{-7}	2.8×10^{-6}	7.1×10^{-8}	8.0×10^{-6}	1.1×10^{-6}	-	sq.ft.• cl.d.d.
Process	-	-	-	-	-	7.1	sq.ft.• year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 2-13

ESTIMATED NATIONAL INDUSTRIAL LAND USE BASED EMISSION FACTORS BY TWO DIGIT 1967 STANDARD INDUSTRIAL CLASSIFICATION CODE

	pounds of pollutant (or kWh·of electricity) per floor area sq.ft.·year					
SIC Code	PM	SO_x	CO	HC	NO_x	J
20	.64	.50	.013	.0033	.13	38
21	1.22	1.02	.025	.014	.23	48
22	.58	.54	.014	.0081	.14	68
23	.06	.04	.0014	.00084	.015	16
24	.06	.07	.0034	.0023	.045	22
25	.11	.08	.0022	.0012	.021	14
26	3.12	3.09	.069	.040	.69	85
27	.01	.02	.00068	.00048	.0095	25
28	.10	.46	.011	.0081	.16	181
29	1.06	2.78	.055	.038	.73	426
30	.51	.38	.010	.0058	.097	50
31	.17	.17	.0047	.0029	.052	18
32	4.03	2.67	.72	.038	.61	78
33	3.06	2.38	.061	.034	.57	297
34	.14	.12	.0035	.0021	.036	33
35	.22	.18	.0047	.0027	.046	31
36	.22	.20	.0053	.0032	.056	56
37	.68	.48	.013	.0068	.11	54
38	.95	.70	.018	.0095	.15	38
19 & 39	.08	.13	.0035	.0024	.044	31

Note: The following is assumed:
2% sulfur in coal
10% ash in coal

0.2% sulfur in distillate oil
1.75% sulfur in residual oil

1967 SIC codes are used because of data availability. The 1972 SIC code manual provides conversions between 1967 and 1972 codes [39].

TABLE 2-14

SINGLE FAMILY RESIDENTIAL LAND USE BASED EMISSION FACTORS (SI UNITS)

		kilogram of pollutant (or Joules of electricity) per measure					
Activity	PM	SO_x	CO	HC	NO_x	J	Measure
Space Heating							
Electricity		-	-	-	-	$2.5 \times 10^{+7}$	dwelling unit•ht.d.d.,°K
Gas	2.1×10^{-4}	1.2×10^{-5}	4.2×10^{-4}	1.6×10^{-4}	2.1×10^{-3}	-	dwelling unit•ht.d.d.,°K
Oil	1.8×10^{-3}	$2.6 \times 10^{-2}S$	9.0×10^{-4}	5.4×10^{-4}	2.1×10^{-3}	-	dwelling unit•ht.d.d.,°K
Air Conditioning							
Central							
Electricity	-	-	-	-	-	$1.7 \times 10^{+7}$	dwelling unit•op.hr.
Gas	8.2×10^{-5}	5.0×10^{-6}	1.6×10^{-4}	6.4×10^{-5}	8.2×10^{-4}	-	dwelling unit•op.hr.
Room							
Electricity	-	-	-	-	-	$1.8 \times 10^{+6}$	dwelling unit•op.hr.
Process							
Hot Water							
Electricity	-	-	-	-	-	$4.9 \times 10^{+10}$	dwelling unit•year
Gas	1.4×10^{-1}	8.2×10^{-3}	2.7×10^{-1}	1.1×10^{-1}	1.4	-	dwelling unit•year
Oil	1.1	$1.7 \times 10^{+1}S$	5.4×10^{-1}	3.4×10^{-1}	1.4	-	dwelling unit•year
Cooking							
Electricity	-	-	-	-	-	$1.3 \times 10^{+10}$	dwelling unit•year
Gas	5.0×10^{-2}	3.0×10^{-3}	1.0×10^{-1}	4.0×10^{-2}	5.0×10^{-1}	-	dwelling unit•year
Miscellaneous	-	-	-	-		$2.8 \times 10^{+10}$	dwelling unit•year

Note: A 149 square meter dwelling unit is assumed.

'S' represents the sulfur percentage of oil, by weight.

TABLE 2-15

MOBILE HOME RESIDENTIAL LAND USE BASED EMISSION FACTORS (SI UNITS)

Activity	PM	kilogram of pollutant (or Joules) per measure					Measure
		SO_x	CO	HC	NO_x	J	
Space Heating							
Electricity	-	-	-	-	-	$1.5 \times 10^{+7}$	dwelling unit·ht.d.d.,°K
Gas	1.4×10^{-4}	8.1×10^{-6}	2.7×10^{-4}	1.1×10^{-4}	1.4×10^{-3}	-	dwelling unit·ht.d.d.,°K
Oil	1.1×10^{-3}	$1.6 \times 10^{-2}S$	5.6×10^{-4}	3.4×10^{-4}	1.4×10^{-3}	-	dwelling unit·ht.d.d.,°K
Air Conditioning							
Central							
Electricity	-	-	-	-	-	$1.2 \times 10^{+7}$	dwelling unit·op.hr.
Room							
Electricity	-	-	-	-	-	$1.8 \times 10^{+6}$	dwelling unit·op.hr.
Process							
Hot Water							
Electricity	-	-	-	-	-	$4.9 \times 10^{+10}$	dwelling unit·year
Gas	1.4×10^{-1}	8.2×10^{-3}	2.7×10^{-1}	1.1×10^{-1}	1.4	-	dwelling unit·year
Oil	1.1	$1.7 \times 10^{-1}S$	5.4×10^{-1}	3.4×10^{-1}	1.4	-	dwelling unit·year
Cooking							
Electricity	-	-	-	-	-	$1.3 \times 10^{+10}$	dwelling unit·year
Gas	5.0×10^{-2}	3.0×10^{-3}	1.0×10^{-1}	4.0×10^{-2}	5.0×10^{-1}	-	dwelling unit·year
Miscellaneous	-	-	-	-	-	$2.8 \times 10^{+10}$	dwelling unit·year

Note: A 67 square meter dwelling unit is assumed.

'S' represents the sulfur percentage of oil, by weight.

TABLE 2-16

LOW RISE MULTIFAMILY RESIDENTIAL LAND USE BASED EMISSION FACTORS (SI UNITS)

Activity	kilogram of pollutant (or Joules) per measure PM	SO_x	CO	HC	NO_x	J	Measure
Space Heating							
Electricity	-	-	-	-	-	$8.4 \times 10^{+6}$	dwelling unit•ht.d.d.,°K
Gas	9.8×10^{-5}	6.0×10^{-6}	2.0×10^{-4}	7.9×10^{-5}	9.8×10^{-4}	-	dwelling unit•ht.d.d.,°K
Oil	9.0×10^{-4}	$1.4 \times 10^{-2}S$	4.7×10^{-4}	2.8×10^{-4}	1.1×10^{-3}	-	dwelling unit•ht.d.d.,°K
Air Conditioning							
Central							
Electricity	-	-	-	-	-	$5.4 \times 10^{+6}$	dwelling unit•op.hr.
Gas	2.8×10^{-5}	1.7×10^{-6}	5.4×10^{-3}	2.3×10^{-5}	2.8×10^{-4}	-	dwelling unit•op.hr.
Oil	2.0×10^{-4}	$2.9 \times 10^{-3}S$	1.0×10^{-4}	5.9×10^{-5}	2.4×10^{-4}	-	dwelling unit•op.hr.
Room							
Electricity	-	-	-	-	-	$1.8 \times 10^{+6}$	unit•op.hr.
Process							
Hot Water							
Electricity	-	-	-	-	-	$4.0 \times 10^{+10}$	dwelling unit•year
Gas	1.1×10^{-1}	6.4×10^{-3}	2.2×10^{-1}	8.6×10^{-2}	1.1	-	dwelling unit•year
Oil	9.1×10^{-1}	$1.3 \times 10^{+1}S$	4.5×10^{-1}	2.7×10^{-1}	1.1	-	dwelling unit•year
Cooking, Dryer							
Electricity	-	-	-	-	-	$1.4 \times 10^{+10}$	dwelling unit•year
Gas	5.4×10^{-2}	3.3×10^{-3}	1.1×10^{-1}	4.4×10^{-2}	5.4×10^{-1}	-	dwelling unit•year
Miscellaneous	-	-	-	-		$1.6 \times 10^{+10}$	dwelling unit•year

Note: An 84 square meter dwelling unit is assumed.

'S' represents the sulfur percentage of oil, by weight.

TABLE 2-17

HIGH RISE MULTIFAMILY RESIDENTIAL LAND USE BASED EMISSION FACTORS (SI UNITS)

Activity	kilogram of pollutant (or Joules of electricity) per measure PM	SO_x	CO	HC	NO_x	J	Measure
Space Heating							
Electricity	-	-	-	-	-	$7.5 \times 10^{+6}$	dwelling unit•ht.d.d.,°K
Gas	8.2×10^{-5}	5.1×10^{-6}	1.7×10^{-4}	6.8×10^{-5}	8.2×10^{-4}	-	dwelling unit•ht.d.d.,°K
Oil	8.2×10^{-4}	$1.2 \times 10^{-2}S$	4.2×10^{-4}	2.5×10^{-4}	1.1×10^{-3}	-	dwelling unit•ht.d.d.,°K
Air Conditioning							
Central							
Electricity	-	-	-	-	-	$5.4 \times 10^{+6}$	dwelling unit•op.hr.
Room							
Electricity	-	-	-	-	-	$1.8 \times 10^{+6}$	dwelling unit•op.hr.
Process							
Hot Water							
Electricity	-	-	-	-	-	$2.2 \times 10^{+10}$	dwelling unit•year
Gas	6.4×10^{-2}	3.8×10^{-3}	1.3×10^{-1}	5.0×10^{-2}	6.4×10^{-1}	-	dwelling unit•year
Oil	5.0×10^{-1}	7.3S	2.6×10^{-1}	1.5×10^{-1}	6.4×10^{-1}	-	dwelling unit•year
Cooking, Dryer							
Electricity	-	-	-	-	-	$1.4 \times 10^{+10}$	dwelling unit•year
Gas	5.4×10^{-2}	3.3×10^{-3}	1.1×10^{-1}	4.4×10^{-2}	5.4×10^{-1}	-	dwelling unit•year
Miscellaneous	-	-	-	-	-	$s.1 \times 10^{+10}$	dwelling unit•year

Note: An 84 square meter dwelling unit is assumed.

'S' represents the sulfur percentage of oil, by weight.

TABLE 2-18

RETAIL ESTABLISHMENTS, WAREHOUSES, WHOLESALING ESTABLISHMENTS, LAND USE BASED EMISSION FACTORS (SI UNITS)

	kilogram of pollutant (or Joules of electricity) per measure						
Activity	PM	SO_x	CO	HC	NO_x	J	Measure
Space Heating							
Electricity	-	-	-	-	-	$9.1 \times 10^{+4}$	m^2•ht.d.d.,°K
Gas	8.6×10^{-7}	5.2×10^{-8}	1.8×10^{-6}	6.9×10^{-7}	8.6×10^{-7}	-	m^2•ht.d.d.,°K
Oil	1.5×10^{-5}	$1.1 \times 10^{-4}S$	2.5×10^{-6}	2.9×10^{-4}	3.9×10^{-5}	-	m^2•ht.d.d.,°K
Air Conditioning							
Electricity	-	-	-	-	-	$3.6 \times 10^{+5}$	m^2•cl.d.d.,°K
Process							
Hot Water							
Electricity	-	-	-	-	-	$1.9 \times 10^{+7}$	m^2• year
Gas	1.2×10^{-4}	6.8×10^{-6}	2.3×10^{-4}	9.3×10^{-5}	1.2×10^{-3}	-	m^2• year
Oil	2.5×10^{-3}	$1.8 \times 10^{-2}S$	4.4×10^{-4}	4.9×10^{-2}	6.8×10^{-3}	-	m^2• year
Lighting	-	-	-	-	-	$3.1 \times 10^{+8}$	m^2• year
Auxiliary Equipment	-	-	-	-	-	$1.4 \times 10^{+8}$	m^2• year
Appliances	-	-	-	-	-	$7.8 \times 10^{+7}$	m^2• year
Refrigeration	-	-	-	-	-	$3.4 \times 10^{+8}$	m^2• year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 2-19

OFFICE BUILDINGS, LAND USE BASED EMISSION FACTORS (SI UNITS)

Activity	kilogram of pollutant (or Joules of electricity) per measure						Measure
	PM	SO_x	CO	HC	NO_x	J	
Space Heating							
Electricity	-	-	-	-	-	$1.3 \times 10^{+5}$	m^2•ht.d.d.,°K
Gas	8.3×10^{-7}	4.9×10^{-8}	1.7×10^{-6}	6.6×10^{-7}	8.3×10^{-6}	-	m^2•ht.d.d.,°K
Oil	1.5×10^{-5}	$1.1 \times 10^{-4}S$	2.5×10^{-6}	2.9×10^{-4}	2.9×10^{-4}	-	m^2•ht.d.d.,°K
Air Conditioning							
Electricity	-	-	-	-	-	$1.0 \times 10^{+5}$	m^2•cl.d.d.,°K
Gas	6.5×10^{-7}	3.9×10^{-8}	1.3×10^{-6}	5.2×10^{-7}	6.5×10^{-6}	-	m^2•cl.d.d.,°K
Oil	1.1×10^{-5}	$8.0 \times 10^{-5}S$	2.0×10^{-6}	2.3×10^{-4}	3.0×10^{-5}	-	m^2•cl.d.d.,°K
Process	-	-	-	-	-	$1.1 \times 10^{+9}$	m^2•year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 2-20

NONHOUSEKEEPING RESIDENTIAL LAND USE BASED EMISSION FACTORS (SI UNITS)

	kilogram of pollutant (or Joules of electricity) per measure						
Activity	PM	SO_x					
Space Heating							
Electricity	-	-	-	-	-	$1.2 \times 10^{+5}$	m^2•ht.d.d.,°K
Gas	3.9×10^{-7}	4.0×10^{-8}	1.7×10^{-6}	6.6×10^{-7}	8.3×10^{-6}	-	m^2•ht.d.d.,°K
Oil	1.2×10^{-5}	$8.7 \times 10^{-5}S$	2.2×10^{-6}	2.5×10^{-4}	2.5×10^{-4}	-	m^2•ht.d.d.,°K
Air Conditioning							
Electricity	-	-	-	-	-	$3.3 \times 10^{+4}$	m^2• year
Gas	2.0×10^{-7}	1.2×10^{-8}	4.0×10^{-7}	1.6×10^{-7}	2.0×10^{-6}	-	m^2• year
Oil	3.6×10^{-7}	$2.5 \times 10^{-6}S$	6.2×10^{-7}	7.0×10^{-5}	9.7×10^{-6}	-	m^2• year
Process	-	-	-	-	-	$4.7 \times 10^{+8}$	m^2• year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 2-21

HOSPITAL, LAND USE BASED EMISSION FACTORS (SI UNITS)

Activity	kilogram of pollutant (or Joules of electricity) per measure						Measure
	PM	SO_x	CO	HC	NO_x	J	
Space Heating							
Electricity	-	-	-	-	-	$1.5 \times 10^{+5}$	m^2•ht.d.d.,°K
Gas	1.6×10^{-6}	9.7×10^{-8}	3.3×10^{-6}	1.3×10^{-6}	1.6×10^{-5}	-	m^2•ht.d.d.,°K
Oil	2.9×10^{-6}	$2.0 \times 10^{-5}S$	5.1×10^{-6}	5.8×10^{-4}	7.6×10^{-5}	-	m^2•ht.d.d.,°K
Air Conditioning							
Electricity	-	-	-	-	-	4.1×10^{-5}	m^2•cl.d.d.,°K
Process							
Lighting	-	-	-	-	-	$5.8 \times 10^{+8}$	m^2• year
Auxiliary Equipment	-	-	-	-	-	$6.6 \times 10^{+8}$	m^2• year
Appliances	-	-	-	-	-	$2.3 \times 10^{+8}$	m^2• year
Hot Water							
Electricity	-	-	-	-	-	$1.9 \times 10^{+8}$	m^2• year
Gas	1.2×10^{-3}	6.8×10^{-5}	2.3×10^{-3}	9.3×10^{-4}	1.2×10^{-2}	-	m^2• year
Oil	2.5×10^{-2}	$1.8 \times 10^{-1}S$	4.4×10^{-3}	4.9×10^{-1}	6.8×10^{-2}	-	m^2• year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 2-22

CULTURAL BUILDINGS LAND USE BASED EMISSION FACTORS (SI UNITS)

Activity	kilogram of pollutant (or Joules of electricity) per measure						Measure
	PM	SO_x	CO	HC	NO_x	J	
Space Heating							
Electricity	-	-	-	-	-	$1.3 \times 10^{+5}$	m^2•ht.d.d.,°K
Gas	7.9×10^{-7}	4.7×10^{-8}	1.6×10^{-6}	6.3×10^{-7}	7.9×10^{-6}	-	m^2•ht.d.d.,°K
Oil	1.4×10^{-5}	$9.7 \times 10^{-5}S$	2.5×10^{-6}	2.8×10^{-4}	3.7×10^{-5}	-	m^2•ht.d.d.,°K
Air Conditioning							
Electricity	-	-	-	-	-	$4.1 \times 10^{+4}$	m^2•cl.d.d.,°K
Gas	2.5×10^{-7}	1.5×10^{-8}	5.0×10^{-7}	2.0×10^{-7}	2.5×10^{-6}	-	m^2•cl.d.d.,°K
Oil	4.5×10^{-6}	$3.2 \times 10^{-5}S$	7.8×10^{-7}	8.8×10^{-5}	1.1×10^{-5}	-	m^2•cl.d.d.,°K
Process	-	-	-	-	-	$4.7 \times 10^{+8}$	m^2•year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 2-23

CHURCH BUILDINGS LAND USE BASED EMISSION FACTORS (SI UNITS)

Activity	kilogram of pollutant (or Joules of electricity) per measure PM	SO_x	CO	HC	NO_x	J	Measure
Space Heating							
Electricity	-	-	-	-	-	$2.0 \times 10^{+5}$	m^2•ht.d.d.,°K
Gas	1.2×10^{-6}	7.6×10^{-8}	2.5×10^{-6}	9.7×10^{-7}	1.2×10^{-5}	-	m^2•ht.d.d.,°K
Oil	2.3×10^{-5}	$1.6 \times 10^{-4}S$	4.0×10^{-6}	4.4×10^{-4}	5.9×10^{-5}	-	m^2•ht.d.d.,°K
Air Conditioning							
Electricity	-	-	-	-	-	$2.7 \times 10^{+5}$	m^2•cl.d.d.,°K
Gas	1.6×10^{-6}	9.7×10^{-8}	3.3×10^{-6}	1.3×10^{-6}	1.6×10^{-5}	-	m^2•cl.d.d.,°K
Oil	2.9×10^{-5}	$2.0 \times 10^{-4}S$	5.0×10^{-6}	5.6×10^{-4}	7.6×10^{-4}	-	m^2•cl.d.d.,°K
Process	-	-	-	-	-	$1.6 \times 10^{+8}$	m^2•year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 2-24

SCHOOL BUILDINGS LAND USE BASED EMISSION FACTORS (SI UNITS)

Activity	PM	SO_x	CO	HC	NO_x	J	Measure
	kilogram of pollutant (or Joules of electricity) per measure						
Space Heating							
Electricity	-	-	-	-	-	$1.2 \times 10^{+5}$	m^2•ht.d.d.,°K
Gas	7.0×10^{-7}	4.2×10^{-8}	1.4×10^{-6}	5.6×10^{-7}	7.0×10^{-6}	-	m^2•ht.d.d.,°K
Oil	1.1×10^{-5}	$7.5 \times 10^{-5}S$	1.8×10^{-6}	2.1×10^{-4}	2.8×10^{-5}	-	m^2•ht.d.d.,°K
Air Conditioning							
Electricity	-	-	-	-	-	$3.3 \times 10^{+4}$	m^2•cl.d.d.,°K
Gas	2.0×10^{-8}	1.2×10^{-8}	4.0×10^{-7}	1.6×10^{-7}	2.0×10^{-6}	-	m^2•cl.d.d.,°K
Oil	3.6×10^{-6}	$2.5 \times 10^{-5}S$	6.2×10^{-7}	7.0×10^{-5}	9.7×10^{-6}	-	m^2•cl.d.d.,°K
Process	-	-	-	-	-	$2.8 \times 1^{+8}$	m^2•year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 2-25

ESTIMATED NATIONAL INDUSTRIAL LAND USE BASED EMISSION FACTORS BY 2 DIGIT 1967 STANDARD INDUSTRIAL CLASSIFICATION CODE

	kilograms of pollutant (or Joules of electricity) per floor area square meter-year					
	PM	SO_x	CO	HC	NO_x	J
20	3.12	2.44	.06	.02	.63	1.5×10^9
21	5.96	4.98	.12	.07	1.12	1.9×10^9
22	2.83	2.64	.07	.04	.68	2.6×10^9
23	.29	.20	.01	.004	.07	6.2×10^8
24	.29	.34	.02	.01	.22	8.5×10^8
25	.54	.39	.01	.01	.10	5.4×10^8
26	15.23	15.09	.34	.20	3.37	3.3×10^9
27	.05	.10	.003	.002	.05	9.7×10^8
28	.48	2.25	.05	.04	.78	7.0×10^9
29	5.17	13.57	.27	.19	3.56	1.7×10^{10}
30	2.49	1.86	.05	.03	.47	1.0×10^9
31	.83	.83	.02	.01	.25	7.0×10^8
32	19.67	13.03	3.52	.19	2.98	3.0×10^9
33	14.94	11.62	.30	.17	2.78	1.2×10^{10}
34	.68	.59	.02	.01	.18	1.3×10^9
35	1.07	.88	.02	.01	.22	1.2×10^9
36	1.07	.98	.03	.02	.27	2.2×10^9
37	3.32	2.34	.06	.03	.54	2.1×10^9
38	4.64	3.42	.09	.05	.73	1.5×10^9
39 & 19	.39	.63	.02	.01	.21	1.2×10^9

Note: The following is assumed: 2% sulfur in coal
10% ash in coal

0.2% sulfur in distillate oil
1.75% sulfur in residual oil

III. DEVELOPMENT OF EMISSION FACTORS

The critical element in the development of the land use based emission factors is the development of energy requirements per square foot for various building types. The remainder of the information needed for the emission factor generally is available.

Much of the existing literature on energy consumption in buildings is not applicable to the development of energy requirement factors. Most of it is devoted to predicting the energy consumption of a single structure. The literature that is applicable to this study falls into two classes: 1) typical energy consumption of a building category based on engineering estimates, and 2) average energy consumption from a sample of structures in a building category. Both classes of literature are used in the following analysis with slightly more emphasis given to the latter category.

A. RESIDENTIAL

A recent and comprehensive example of an engineering estimate is the Task Force Report on Residential and Commercial Energy Use Patterns prepared for Project Independence [12]. Typical construction for various classes of buildings was identified in each of four Census Regions. Standard engineering estimates of energy consumption were then prepared, based on the climatology of an average city in each region. Using estimates of heating degree days and compressor operating hours (shown in Table 3-1), Walden prepared estimates of energy consumption per degree day and operating hour, as shown in Table 3-2.

1. Single Family Residential

Aside from the Project Independence estimates, the following sources were obtained. This is not a comprehensive list, but, within the scope of this project, it is what could be obtained. In our opinion, it is representative of energy consumption in buildings.

TABLE 3-1

RESIDENTIAL DESIGN PARAMETERS

City	Heating Degree Days	Compressor Operating Hours
Northeast Norwalk, Connecticut	5,400	300
North Central Region Detroit, Michigan	6,200	500
South Pine Bluff, Arkansas	2,800	1,600
West Roswell, New Mexico	3,800	1,600

Note: Reference 12 and Figures 1-1 and 1-3.

TABLE 3-2

ENGINEERING ESTIMATES OF REGIONAL SPACE HEATING AND AIR CONDITIONING ENERGY CONSUMPTION

Building Type	Space Heating (Btu/sq.ft.-dd)			Cooling (Btu/sq.ft.-hour)	
	Electric	Gas	Oil	Electric	Gas/Oil
Mobile Homes					
North East	11.8	23.3	27.2	15.7	--
North Central	11.6	23.5	27.3	16.4	--
South	12.3	24.8	28.9	16.7	--
West	10.9	22.3	26.0	16.2	--
Single Family Detached					
North East 1 Story	7.9	21.9	25.5	7.5	8.5
2 Stories	7.9	20.7	24.2	8.3	9.8
North Central 1 Story	7.8	21.2	24.8	7.7	9.0
2 Stories	7.7	20.3	23.7	8.3	9.7
South 1 Story	8.5	19.4	--	11.3	12.8
2 Stories	8.1	18.6	--	11.2	12.1
West 1 Story	8.2	19.1	--	11.6	12.6
2 Stories	8.2	18.5	--	11.4	12.8
Single Family Attached					
North East 1 Story	7.7	21.1	24.6	7.3	8.2
2 Stories	6.3	18.0	20.9	6.7	9.7
North Central 1 Story	7.6	22.9	26.7	7.5	9.6
2 Stories	7.6	19.6	22.8	8.2	9.5
South 1 Story	7.6	19.0	--	10.4	12.6
2 Stories	7.9	17.1	--	11.2	11.4
West 1 Story	7.3	16.8	--	10.4	11.1
2 Stories	8.3	17.0	--	11.6	11.8
Low Rise					
North East	4.9	15.2	17.7	4.8	5.9
North Central	4.9	15.5	18.0	4.9	6.4
South	4.9	12.1	--	6.5	8.0
West	4.8	11.2	--	6.9	7.4
High Rise					
North East	4.4	14.1	16.4	2.4	3.3
North Central	4.2	14.0	16.3	6.0	4.2
South	4.1	10.8	--	5.5	7.1
West	4.3	9.6	--	6.0	6.3

a. Space Heating

The report on residential appliance gas consumption in Lincoln, Sioux Falls, Minneapolis, and Omaha by the Northern Natural Gas (NNG) Company [13] contains the results of actual measurements of the consumption of gas for space heating in single-family dwellings. Their analysis resulted in the values of gas consumption per square foot degree day shown below.

Size of Dwelling (sq.ft.)	Gas, cubic feet/sq.ft.-d.d.	Gas, Btu/sq.ft.-d.d.
800	0.0214	22.08
1000	0.0181	18.68
1200	0.0159	16.40
1400	0.0143	14.76
1600	0.0131	13.52
1800	0.0122	12.59
2000	0.0115	11.87

This is based on the following equation, derived by regression analysis on their sample,

$$\text{Gas consumption, Btu} = -40{,}572{,}100 + (18{,}614.3 * \text{ht.d.d.}) + (36{,}000 * \text{sq.ft.})$$

These data show a lower consumption than the estimate derived from the Project Independence study, 20.3 British thermal units per square foot degree day for a 1600 square foot dwelling.

The Hittman Associates report [14] estimated the annual heating requirement of a characteristic house in the Baltimore area to be 710 therms. At 4600 degree days and a finished floor area of 1695 square feet, this represents 9.106 British thermal units per square foot degree day of heat requirement. Hittman Associates then assumed a 70 percent efficiency to obtain a gas requirement of 1014 therms, or 13.0 Btu/square foot degree day. At 1032 Btu/cu.ft., this represents 0.0126 cubic foot per square foot degree day; this compares very favorably with the Northern Natural Gas data.

Community residential gas sales figures were obtained from several gas companies. The gas distribution companies listed below provided data.

Company	Year of Data	States Served
San Diego Gas and Electric	1965-1973	California
Public Service Company of Colorado	1970, 1971, 1972, 1973	Colorado
Pacific Gas and Electric	1973	California
Rochester Gas and Electric	1972, 1973	New York
Baltimore Gas and Electric	1972, 1973	Maryland
Boston Gas	1971, 1972, 1973	Massachusetts
East Ohio Gas Company	1972, 1973	Ohio
Peoples Gas Company	1973	Nebraska, Iowa, Minnesota, Kansas
Southern Union Gas Company	1970, 1971	Arizona, Texas, New Mexico, Colorado

The listed gas companies provided Walden with the total natural gas consumption and number of customers in approximately one thousand communities. This was reduced to a sample of 278 cities, towns, and counties which contained a reporting weather station. A scatter diagram of degree days and therms per housing unit is shown in Figure 3-1. Each occurrence of a '1' represents a single observation while a number other than '1' indicates more than one observation at that point. Based on the relative proportion of gas customers with other gas appliances [15] and the estimated consumption of these appliances,* the average gas consumption per customer for space heat was estimated. The regression of space heat therms per dwelling units on degree days produced:

$$\text{Therms per dwelling unit} = 747.2 + .1050 * \text{ht.d.d.}$$

$$R^2 = .344 \qquad F\ (1,223) = 100$$

At 5000 degree days and 1600 square feet, this is approximately 16 British thermal units per square foot degree day.

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*See following section on residential process energy consumption.

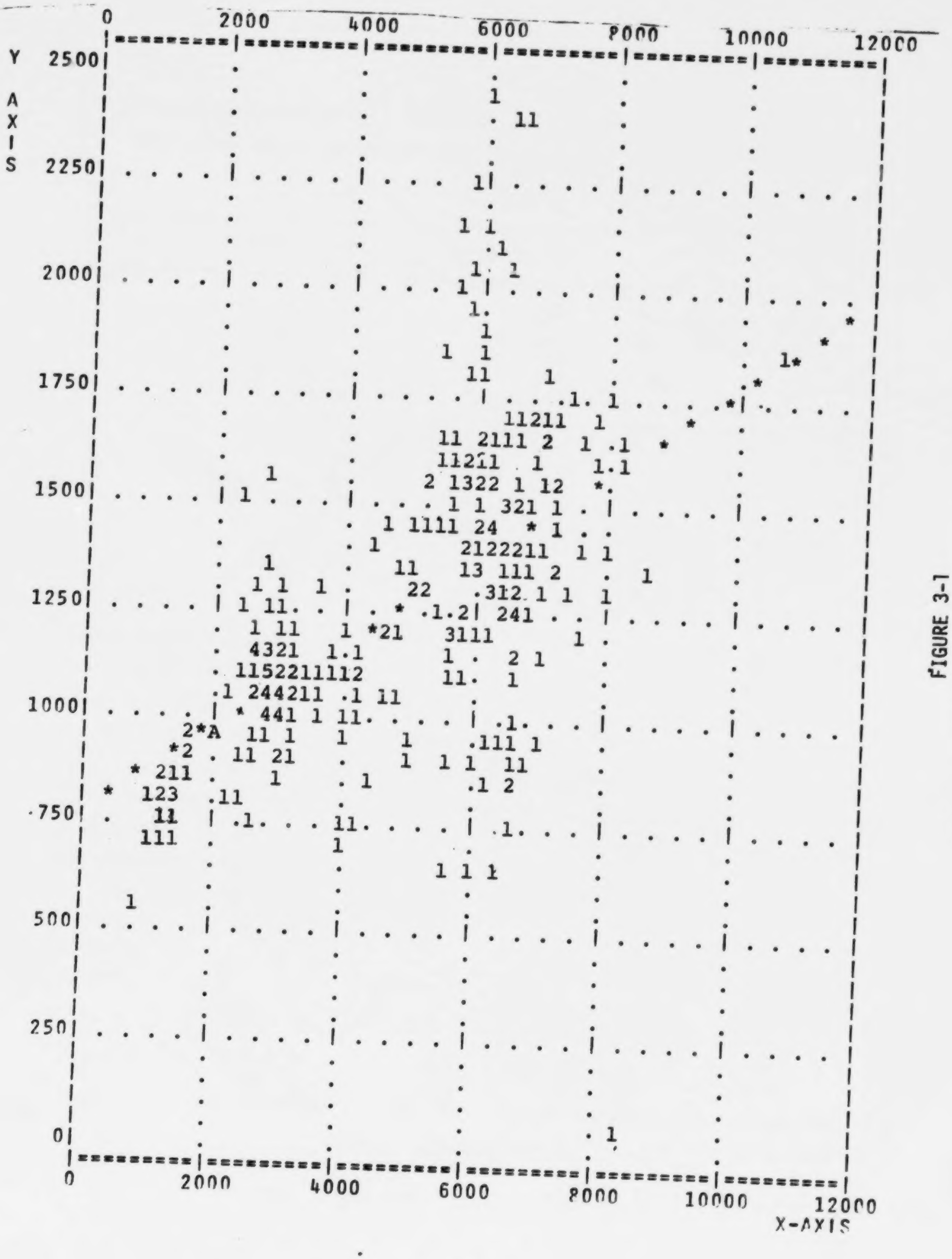

FIGURE 3-1
SCATTER DIAGRAM OF DEGREE DAYS (X-AXIS) AND

Finally, in Volume 13 of the AQMP Guidelines Series [16], the EPA suggests the use of 17,000 British thermal units per single family dwelling degree day in the subcounty allocation of residential fuels (and emissions). The use of efficiencies of 80 percent and 75 percent for gas and oil are suggested. We believe these to be too high for utilization efficiencies. At efficiencies of 60 percent and 50 percent and an assumed 1600 square foot house, this represents approximately 18 and 21 British thermal units per square foot degree day. For electric heat, with a utilization efficiency of 1.0, this would be about 10.5 British thermal units per square foot degree day.

The foregoing estimates are shown in Figure 3-2. The FEA engineering estimates exceed the EPA estimate, the Hittman estimate, the Walden sample and the Northern Natural Gas sample. Given the size of the Walden sample, we consider 16 British thermal units per square foot degree day the best estimate of single family residential gas consumption. The Northern Natural Gas sample can be discounted because of its sample size and its origin in a high degree day area. Their results do suggest that one should consider adjusting downward the selected 16 British thermal units per square foot value in cold climates (e.g., above 7000 degree days) or where the average dwelling unit size is significantly above 1600 square feet. Correspondingly, the 16 British thermal units per square foot degree day figure is probably unrepresentative of low degree day area.

Considering the data on gas, it is probable that the FEA estimate for oil is also too high. The EPA figure is also high assuming 16 British thermal units per square foot degree days is the correct figure for gas. Assuming it is correct, and assuming utilization efficiencies of .6 and .5, the corresponding estimate for oil would be:

$$16 \frac{.6}{.5} = 19.2$$

The FEA figure for electric heat will be used, approximately 8 Btu/sq.ft.-d.d.

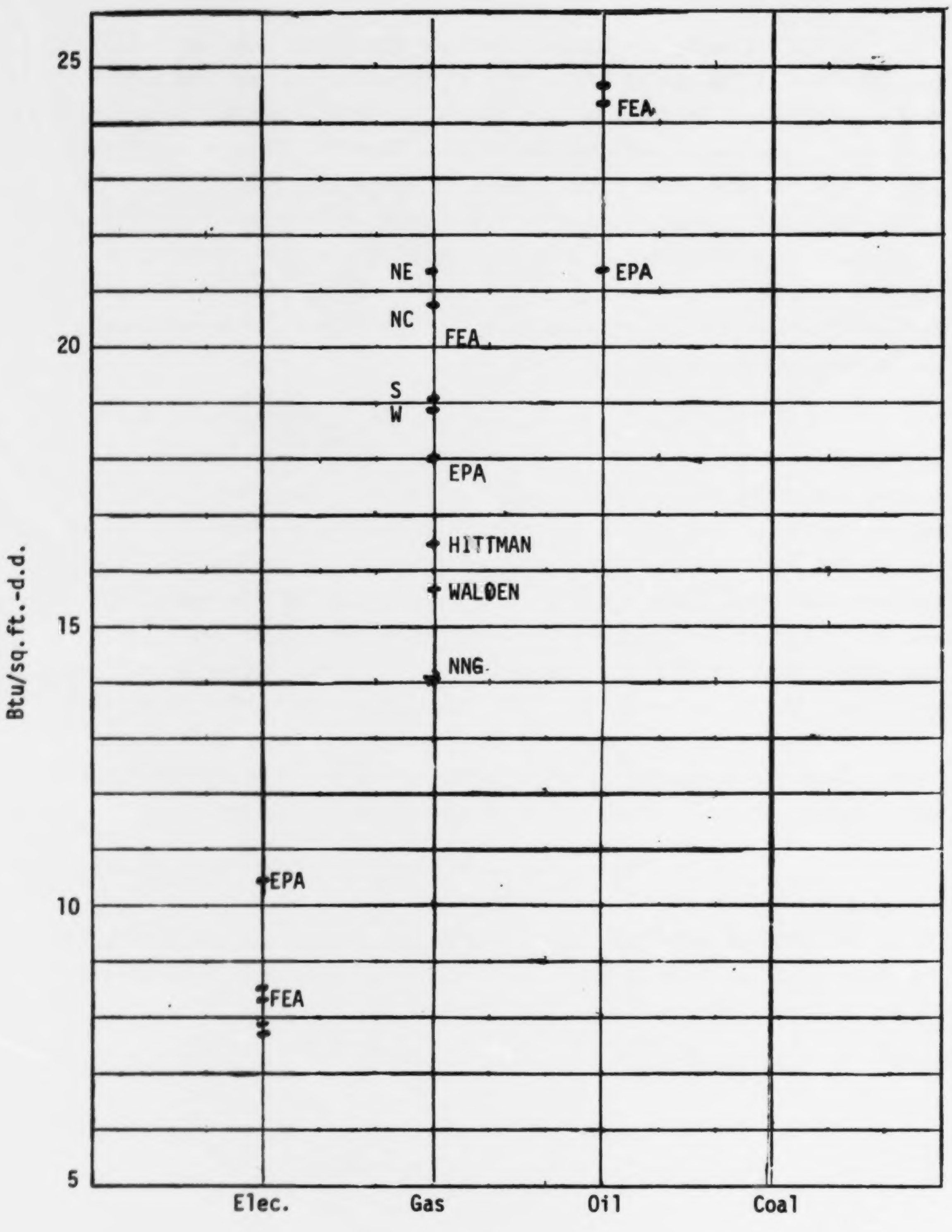

FIGURE 3-2. ESTIMATES OF SINGLE FAMILY RESIDENTIAL SPACE HEATING ENERGY DEMAND BY FUEL TYPE.

b. Air Conditioning Central

The Hittman report [14] estimates an annual cooling requirement of 282 therms for the same characteristic house in the Baltimore area. At 1058 cooling degree days and 1695 square feet, this is equivalent to 15.725 British thermal units per square foot degree day or, at 1000 operating hours,* 16.6 British thermal units per square foot hour. This is higher than the Project Independence estimate of 11.3 British thermal units per square foot hour. No other relevant data on central air conditioning energy consumption was readily available. Admittedly, there is little basis for using either figure, however, the selection of a number is not critical since central air conditioning represents a relatively small proportion of residential energy consumption (about 5 percent of total residential energy consumption [12]). We have selected FEA Project Independence figures.

c. Air Conditioning, Room

The electricity demand due to room air conditioners can be approximated [17] by:

$$\text{air conditioner capacity} * \text{compressor operating hours} * \frac{1}{\text{seasonal energy efficiency ratios (EER)}}$$

The 1970, the average nameplate EER of units in place is reported to be six [12]. We estimate the actual seasonal EER to be about 7 based on reference [17]. The average capacity of units shipped from manufacturers in the first nine months of 1971 is 12,300 British thermal units [17]. Therefore, the average energy consumption per room air conditioner would be approximately:

$$\text{Btu} = 12{,}300 * \text{operating hours} * \frac{1}{7}$$

---

*See Figure 1-3; the operating hours on this figure are approximately the same as the cooling hours used in the Hittman report.

$$\text{Btu} = 1757.14 * \text{operating hours}$$

or the annual Btu consumption per unit operating hour is:

$$1757 \frac{\text{Btu}}{\text{operating hour}}$$

or .51 kWh per operating hour

d. Process Use

The Northern Natural Gas study reported the following consumption for gas appliances:

Occupants	Water Heater Load, cu.ft.	Dryer Load, cu.ft.
2	33,702	4,461
3 (Average)	36,588	5,582
4	39,473	6,702
5	42,358	7,822
6	45,244	8,942
7	48,129	10,062
8	51,014	11,183

In addition, they reported a mean load for gas ranges of 8,249 cu.ft., of which 4,256 cu.ft., was for the pilot light.

The American Gas Association reports the following averages [18] (in units of cubic feet):

Region	Water Heater	Dryer Gas Pilot	Dryer Electric Pilot	Range
New England	23,474	8,924	7,372	9,797
Middle Atlantic	30,846	6,305	6,305	11,349
East North Central	30,749	6,693	5,626	9,797
West North Central	33,077	7,275	5,044	8,439
South Atlantic	34,726	6,402	3,880	9,215
East South Central	27,839	5,820	6,111	12,319
West South Central	30,943	8,051	6,111	10,864
Mountain	25,317	11,640	7,469	9,991
Pacific	31,913	7,760	5,238	9,894
U.S. Average	30,652	7,275	5,820	10,185

Hittman Associates estimated the following process energy use for the characteristic single-family dwelling in the Baltimore area [14]:

Hot water heating	26,162 cu.ft. gas	4,399 kWh electricity
Dryer	3,876 cu.ft. gas	990 kWh electricity
Range	4,844 cu.ft. gas	1,173 kWh electricity
Refrigerator		1,833 kWh
Lights		1,998 kWh
Television		494 kWh
Clothes washer		101 kWh
Dishwasher		367 kWh
Miscellaneous		2,324 kWh

The University of Oklahoma reports the following figures [19]:

hot water, gas	$2.7 * 10^7$ Btu/dwelling unit
hot water, electricity	$4.62 * 10^7$ Btu/dwelling unit
hot water, oil	$3.46 * 10^7$ Btu/dwelling unit
cooking, gas	$1.1 * 10^7$ Btu/dwelling unit
cooking, electric	$1.2 * 10^7$ Btu/dwelling unit

Based on these figures, the process energy consumption has been estimated as shown in Table 3-3. Table 3-3 also summarizes space heating & air conditioning energy demand estimates.

2. Single Family Attached Dwelling Units

On the basis of the close correspondence between the single family attached and single family detached energy consumption estimates in the FEA study [12], we have assumed the values in Table 3-3, to be equally applicable to single family attached housing.

3. Mobile Home Dwelling Units

Data on energy consumption in mobile homes is limited. Due to the lack of better estimate, we have elected to use the FEA estimates for space heat and air conditioning. Process energy consumption has been assumed to be the same as single family detached housing. These values are summarized in Table 3-4.

4. Multifamily Low Rise Residential

As described in Section III.A, the Federal Energy Administration (FEA) Project Independence [12] estimated energy consumption in multifamily low rise dwelling units. The parameters they used are summarized in Table 3-5, and the resulting estimates in Table 3-6.

TABLE 3-3

RESIDENTIAL SINGLE FAMILY DETACHED ENERGY CONSUMPTION

Activity		Btu/Measure	Measure
Spaceheat;	electricity	8.0	square foot • heating degree day
	gas	16.0	square foot • heating degree day
	oil	19.2	square foot • heating degree day
Air conditioning;	central electricity	10.0	square foot • heating degree day
	central, gas	11.0	square foot • heating degree day
	room, electric	1,757	a.c. unit • operating hour
Hot water;	electricity	$4.6 * 10^7$	dwelling unit • year
	gas	$3.0 * 10^7$	dwelling unit • year
	oil	$3.5 * 10^7$	dwelling unit • year
Cooking;	electricity	$1.2 * 10^7$	dwelling unit • year
	gas	$1.1 * 10^7$	dwelling unit • year
Miscellaneous	electricity	$2.7 * 10^7$	dwelling unit • year

Notes: A 1600 square foot house is assumed. Air conditioner operating hours are from Figure 1-3. Electricity consumption is at point of entry; it does not include transmission and generation losses.

TABLE 3-4

MOBILE HOME ENERGY CONSUMPTION

Activity		Btu/Measure	Measure
Spaceheat;	electricity	11.0	square foot • heating degree day
	gas (or LPG)	23.0	square foot • heating degree day
	oil	27.0	square foot • heating degree day
Air conditioning;	central, electricity	16	square foot • heating degree day
	room, electric	1,757	a.c. unit • operating hour
Hot water;	electricity	$4.6 * 10^7$	dwelling unit • year
	gas (or LPG)	$3.0 * 10^7$	dwelling unit • year
	oil	$3.5 * 10^7$	dwelling unit • year
Cooking;	electricity	$1.2 * 10^7$	dwelling unit • year
	gas (or LPG)	$1.1 * 10^7$	dwelling unit • year
Miscellaneous	electricity	$2.7 * 10^7$	dwelling unit • year

Note: Air conditioning operating hours are from Figure 1-3. Electricity consumption is at point of entry; it does not include transmission and generation losses. A 720 square feet per dwelling unit is assumed.

TABLE 3-5

FEA DESIGN PARAMETERS

	FEA Design Parameters Square feet/dwelling unit Low Rise	High Rise	ht.d.d.	Operating Hours	cl.d.d.
NE	900	900	5400	300	729
NC	900	900	6200	500	684
S	900	900	2800	1600	2000
W	900	900	3800	1600	1600

TABLE 3-6

FEA LOW RISE MULTI-FAMILY ESTIMATES

	Region			
	North East	North Central	South	West
Space heating, electric				
MM Btu/unit year	23.8	27.1	12.3	16.5
Btu/sq.ft.-ht.d.d.	4.9	4.9	4.9	4.8
Btu/unit-ht.d.d.	4407	4371	4394	4342
Space heating, gas				
MM Btu/unit-year	73.8	86.3	30.5	38.4
Btu/sq.ft.-ht.d.d.	15.2	15.5	12.1	11.2
Btu/unit-ht.d.d.	13667	13919	10893	10105
Space heating, oil				
MM Btu/unit-year	86.1	100.7		
Btu/sq.ft.-ht.d.d.	17.7	18.0		
Btu/unit-ht.d.d.	15944	16242		
Air conditioning, electric				
MM Btu/unit-year	1.3	2.2	9.3	9.9
Btu/sq.ft.-cl.d.d.	2.0	3.6	5.2	6.9
Btu/unit-cl.d.d.	1783	3216	4650	6188
Air conditioning, gas/oil				
MM Btu/unit-year	1.6	2.9	11.5	10.7
Btu/sq.ft.-cl.d.d.	2.4	4.7	6.4	7.4
Btu/unit-cl.d.d.	2195	4240	5750	6688

a. Space Heating

Hittman Associates, using the same time-response method employed in the single-family energy consumption study, calculated the follow-estimate of low rise multifamily gas space heating energy consumption [20]:

Sq.Ft.	Therms/Sq.Ft.	Btu/Sq.Ft.-ht.d.d., Gas	Btu/Unit-ht.d.d.
1,120	0.419	9.11	10200

This is lower than the FEA Project Independence estimates.

Walden Research obtained a complete set of Electric Heating Association (EHA) case studies [21]. Each case study reported monthly electricity consumption of a specific all electric building. Fourteen of these case studies were low rise apartment buildings. The regression of monthly kilowatt-hours per low rise apartment on the monthly heating and cooling degree days provided the following results*:

$$\frac{\text{kWh}}{\text{unit-month}} = 476.8 + 1.292 * \text{ht.d.d.} + 1.108 * \text{cl.d.d.}$$

$$R^2 = .32 \qquad F\ (2,165) = 39.5$$

This can be restated in Btu's, viz.,

$$\frac{\text{Btu}}{\text{unit-month}} = 1626842 \frac{\text{Btu}}{\text{unit-month}} + 4408 \frac{\text{Btu}}{\text{unit-ht.d.d.}} + 3780 \frac{\text{Btu}}{\text{unit-cl.d.d.}}$$

The 4408 British thermal unit per unit-heating degree day compares favorably with the FEA estimates. Note that the 3780 British thermal unit per unit cooling degree day also compares favorably.

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*Results of the regression analysis on the EHA data is summarized in Appendix C.

TABLE 3-7

COMPARISON OF RELEVANT FEA, EHA, AND HITTMAN DATA

Space heating, Electric		
Average FEA	4373	Btu/unit-ht.d.d.
EHA regression	4408	Btu/unit-ht.d.d.
Space heating, Gas		
FEA, South	10893	Btu/unit-ht.d.d.
Hittman	10200	Btu/unit-ht.d.d.
FEA, South	12.1	Btu/sq.ft.-ht.d.d.
Hittman	9.1	Btu/sq.ft.-ht.d.d.

Comparable values of all three data sources are summarized in Table 3-7. Overall, they compare rather well. We have elected to use the average of the FEA regional estimates for space heating in low rise multifamily dwelling units.

b. Air Conditioning, Central

Hittman Associates estimated the electricity requirements for the same characteristic Baltimore apartments. The calculated per square foot cooling degree day and per unit cooling degree day requirements are shown below.

Sq.Ft.	Therms/Sq.Ft.	Btu/Sq.Ft.-cl.d.d.	Btu/unit-cl.d.d.
1120	0.093	8.79	9900

This is substantially higher than the FEA estimate of 4650 British thermal units cooling degree days estimate for the Southern Region.

As discussed in the previous section, regression analysis of EHA data provided an estimate of 3780 British thermal units cooling degree days. This is near the mean, 3959, of the widely spread FEA data.

We have elected to use the mean of the regional FEA data. As with single family housing, we have used the estimated annual operating hours rather than degree days as the denominator, as reported in Table 3-8.

c. Air Conditioning, Room

The per unit operating hours energy requirements of room air conditioners in low rise multifamily housing is assumed to be the same as the single family detached housing per unit operating hours requirement.

d. Process Energy Requirements

The Hittman Associates study [20] estimated process energy requirements per dwelling unit-year as follows:

Water Heater Gas	Cooking and Clothes Dryer Gas	Miscellaneous	Total
240 Therms	120 Therms	4300 kWh	
$2.4 * 10^7$ Btu	$1.2 * 10^7$ Btu	$1.5 * 10^7$ Btu	$5.1 * 10^7$ Btu

The constant in the EHA regression analysis is 476.8 kWh per dwelling unit per month. On an annual basis this is 5722 kWh or $1.9 * 10^7$ Btu. This is significantly less than the Hittman estimate.

We have elected to use the Hittman estimate, as it appears to be reasonable when compared with the previous estimates for process energy consumption in single family housing. Energy consumption for electric water heating and cooking is derived by using the efficiencies implied in the same uses in single family housing. Energy consumption for low rise multi-family housing is summarized in Table 3-8.

5. Highrise Multi-family Residential

The FEA Project Independence estimates of energy consumption in high rise multi-family residential buildings are shown in Table 3-9.

a. Space Heating

Hittman Associates, using the same time response method employed in the single-family energy consumption study, calculated the following estimates of multifamily gas space heating energy consumption [20]:

Sq.Ft.	Therms/Sq.Ft.	Btu/Sq.Ft.-ht.d.d., Gas	Btu/Apt.-ht.d.d.
972	0.399	8.67	8400

This is substantially lower than the Project Independence estimates.

Gordian Associates, in Environmental Impact of Electric vs. Fossil Fuel Space Heating for the Welfare Island Development Project,

TABLE 3-8

LOW RISE MULTI-FAMILY RESIDENTIAL ENERGY CONSUMPTION

Activity		Btu/Measure	
Space heat;	electricity	4380	dwelling unit - ht.d.d.
	gas	12150	dwelling unit - ht.d.d.
	oil	16100	dwelling unit - ht.d.d.
Air conditioning;	central, electricity	5700	dwelling unit - operating hour
	central, gas or oil	6800	dwelling unit - operating hour
	room, electric	1757	a.c. unit - operating hour
Hot water;	electricity	$3.7 * 10^7$	dwelling unit - year
	gas	$2.4 * 10^7$	dwelling unit - year
	oil	$2.8 * 10^7$	dwelling unit - year
Cooking & Clothes Dryer;	electricity	$1.3 * 10^7$	dwelling unit - year
	gas	$1.2 * 10^7$	dwelling unit - year
Miscellaneous:	electricity	$1.5 * 10^7$	dwelling unit - year

Note: A 900 square foot dwelling unit assessment; air conditioner operating hours are from Figure 1-3.
Electricity consumption is at point of entry; it does not include transmission and generation losses.

TABLE 3-9

FEA HIGH-RISE MULTI-FAMILY RESIDENTIAL ESTIMATES

	NE	North Central	South	West
Space heating, electric				
MM Btu/unit year	21.2	23.3	10.4	14.6
Btu/sq/ft.-ht.d.d.	4.36	4.18	4.13	4.27
Btu/unit-ht.d.d.	3926	3758	3714	3842
Space heating, gas				
MM Btu/unit-year	68.3	78.1	27.1	32.8
Btu/sq.ft-ht.d.d.	14.1	14.0	10.8	9.6
Btu/unit-ht.d.d.	12648	12597	9679	8632
Space heating, oil				
MM Btu/unit-year	79.6	91.1		
Btu/sq/ft.-ht.d.d.	16.4	16.3		
Btu/unit-ht.d.d.	14741	14694		
Air conditioning, electric				
Electric space heater				
MM Btu/unit-year	1.1	2.7	7.9	8.7
Btu/sq.ft.-cl.d.d.	1509	3947	3950	5437
Btu/unit-cl.d.d.	1.68	4.39	4.39	6.04
Btu/unit-operating hour	3667	5400	4938	5437
Air conditioning, electric				
Gas or oil spaceheat				
MM Btu/unit-year	1.5	1.9	10.2	9.1
Btu/sq.ft.-cl.d.d.	2.29	3.09	5.67	6.32
Btu/unit-cl.d.d.	2058	2778	5100	5687
Btu/unit-operating hour	5000	3800	6375	5687

obtained energy consumption data for 18 electrically heated apartment buildings in the eastern United States and Canada. The consumption data in this report are summarized and the Btu per apartment heating degree days ratios are developed in Table 3-10. The average British thermal units per apartment-heating degree day consumed for electrical space heating can be computed two ways, across buildings or across apartments. The calculated averages are, respectively, 3037, and 4452 British thermal units per apartment-heating degree day.

Regression analysis of the high-rise multi-family EHA case studies* indicated a 4872 British thermal units per dwelling unit heating degree day factor.

Finally, Hansteen and Krikwama report in an ASME paper [23] that the energy requirements for electrical space heating in three Brookhaven National Laboratory apartment buildings. The values range from 2.1 to 2.7 kWh per thousand square feet heating degree days with an average of about 2.4. This is equivalent to 8.19 British thermal units per square feet degree day; it is significantly higher than the Gordian Associates data and the Project Independence estimates of electrically heated buildings.

Hansteen and Krikwama also report data on an oil-heated apartment building, identical to one of the electrically heated buildings cited above. They observed an efficiency of utilization of 30%; the oil-heated building consumed 24.37 British thermal units per square feet heated degree days for space heating.

These data are summarized in Figure 3-3. We have elected to use the mean of all estimates for each fuel type, resulting in factors of 3,940,10,400, and 14,700 British thermal units per dwelling unit-heating degree day.

b. Air Conditioning, Central

Hittman Associates estimate of air conditioning electricity requirements for the characteristic Baltimore high rise apartments and the

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*Regression analysis of the EHA case studies is summarized in Appendix C.

TABLE 3-10

ELECTRIC ENERGY CONSUMPTION FOR SPACE HEATING IN 18 APARTMENT BUILDINGS

Building Number	# of Apts.	Degree-days	Space Heat Use kwh x 10^3	BTU per Apt.-dd	KWH per Degree-day
1	495	4,360	4,116	6,510	944
2	435	4,360	2,999	5,397	688
3	500	4,360	4,745	7,429	1,088
4	201	7,060	600	1,443	85
5	200	6,210	601	1,652	97
6	60	6,190	168	1,550	27
7	45	6,600	229	2,633	35
8	117	6,583	765	3,389	116
9	126	5,745	736	3,472	128
10	86	4,987	295	2,344	59
11	60	4,620	139	1,706	30
12	90	8,200	503	2,324	61
13	394	8,200	5,800	6,126	707
14	122	8,200	658	2,246	80
15	205	8,200	555	1,127	68
16	64	9,200	318	1,840	35
17	48	8,200	143	1,241	17
18	46	8,100	244	2,234	30

Average Btu per Apt.-dd: 3,037 Btu per apt.-dd

Average kwh per degree-day divided by number of apts., converted to Btu:
4,452 Btu per apt.-dd

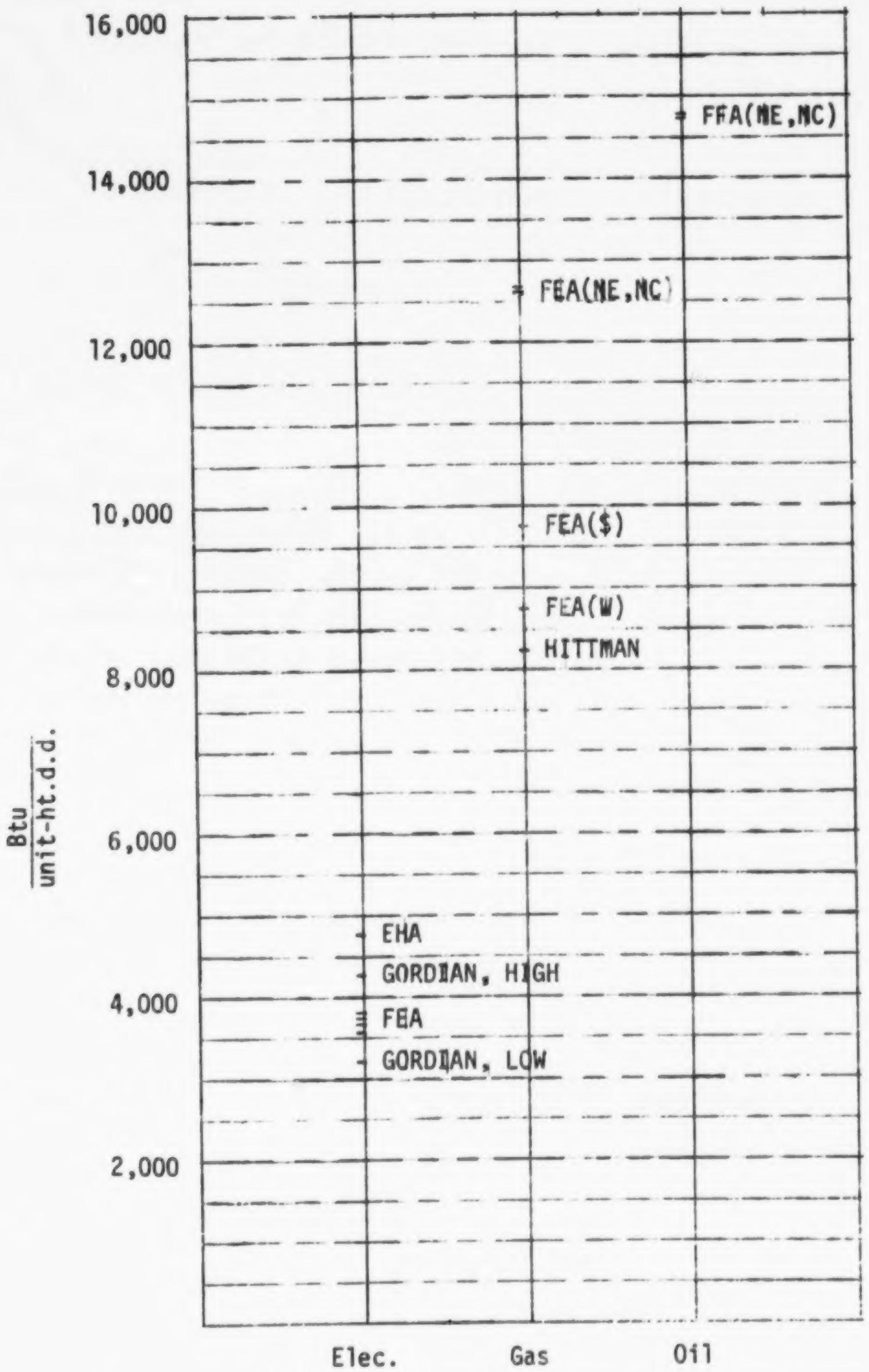

FIGURE 3-3. COMPILATION OF HIGH RISE MULTIFAMILY HEATING ESTIMATES

per square foot-cooling degree day requirements calculated from these requirements are shown below:

Sq.Ft.	Therms/Sq.Ft.	Btu/sq/ft.-cl.d.d.	Btu/unit-cl.d.d.
972	0.052	4.915	4700

The estimate of per unit electricity requirements derived from regression analysis of the EHA case studies is 3780 British thermal units per dwelling unit-cooling degree day.

The EHA regression estimate is relatively close to the mean of the FEA engineering estimates, 3808. The Hittman Associates' estimate is approximately 20% above the FEA and EHA estimates. We find an estimate of 3800 British thermal units per dwelling unit cooling degree day the most reasonable. To maintain consistancy with the other residential air conditioning energy factors, we have elected to use the mean of the FEA estimates in terms of operating hours, (i.e., 5216 British thermal units per dwelling unit operating hour).

c. Air Conditioning, Room

It is assumed the energy requirements of room air conditioners is identical to those in single family room units.

d. Process Energy Requirements

The Hittman Associates estimate of process requirements is as follows:

		per dwelling unit year	
Water Heater Gas	Cooking and Clothes Dryer, Gas	Miscellaneous	Total
144 therms	120 therms	4464 kWh	
1.4×10^7 Btu	1.2×10^7 Btu	2.0×10^7 Btu	$4.6 * 10^7$ Btu

The regression analysis of the EHA data estimated a constant of 493.9 kWh per unit month or 2×10^7 British thermal units per dwelling unit year.

We have elected to use the Hittman estimates in order to be consistent with the low rise multi-family process energy requirements. Energy consumption for electric water heating and cooking is derived by using the efficiencies implied in these uses in single family housing. Energy consumption factors for high rise multi-family housing is summarized in Table 3-11. Note that it is plausable that the EHA regression estimate of process requirement be too low, as the energy factor for space heating that was estimated from the EHA data was higher than the other estimates.

TABLE 3-11

HIGH RISE MULTI-FAMILY RESIDENTIAL ENERGY CONSUMPTION FACTORS

Activity		Btu/Measure	Measure
Space heat;	electricity	3,940	Btu per dwelling unit • heating degree day
	gas	10,400	Btu per dwelling unit • heating degree day
	oil	14,700	Btu per dwelling unit • heating degree day
Air conditioning;	central, electricity	5,200	Btu per dwelling unit • operating hour
	room, electricity	1,757	Btu per air conditioner • operating hour
Hot water	electricity	$2.1 * 10^7$	Btu per dwelling unit • year
	gas	$1.4 * 10^7$	Btu per dwelling unit • year
	oil	$1.6 * 10^7$	Btu per dwelling unit • year
Cooking & Clothes Dryer;	electricity	$1.3 * 10^7$	Btu per dwelling unit • year
	gas	$1.2 * 10^7$	Btu per dwelling unit • year
Miscellaneous;	electricity	$2.0 * 10^7$	Btu per dwelling unit • year

Note A 900 square foot dwelling unit is assumed. Air conditioner operating hours are from Figure 1-3. Electricity consumption is at point of entry; it does not include transmission and generation losses.

B. COMMERCIAL - INSTITUTIONAL

The validity of estimates of average energy requirements of various categories of buildings in the commercial - institutional sector must be treated with more circumspection than the residential estimates discussed in the previous section. Residential heating and central cooling systems are basically the same, and while residential construction is not identical among individual structures or regions of the country, it is reasonably similar within certain limits. Indeed, a large part of the variation in dwelling unit energy demands could be attributed to occupant lifestyle variation. In the commercial - institutional sector, there is a wide variation not only among buildings within a particular category, but also among heating, ventilating, and air conditioning systems.

1. Retail Establishments

The FEA Project Independence study [12] estimated the energy demand of a typical retail establishment in each of four regions. The typical establishment was defined to be a 67,000 square foot, single story surburban mall-type shopping center. The estimated energy demand for this type of structure is shown in Table 3-12, along with the energy consumption per square foot-degree day indices implicit in these estimates.

a. Space heating

The 1958 ASHRAE Handbook [29] reports the steam demand for various retail buildings in units of British thermal units per cubic foot heating degree days. Assuming a ten foot floor to ceiling height, they reported 3.85 British thermal units per square foot heating degree days for department stores and 6.24 British thermal units per square foot heating degree days for other stores.

The Georgia Power Company [23] reports an energy demand for supermarkets of 5.12 British thermal units per square foot heating degree days for electric space heat and 12.62 British thermal units per square foot heating degree days for gas space heat.

TABLE 3-12

FEA ESTIMATES OF RETAIL ESTABLISHMENTS ENERGY DEMAND

	Spaceheating			Air Conditioning
	Electricity	Gas	Oil	Electricity
Demand: MBtu/sq.ft. year				
Northeast	22	52	63	12.2
North Central	26	62	73	12.2
South	14	25	30	29.2
West	16	31	38	19.0
Demand: Btu/sq.ft - d.d.				
Northeast	4.07	9.63	11.67	20.33
North Central	4.19	10.00	11.77	24.40
South	5.00	8.93	10.71	14.60
West	4.21	8.16	10.00	12.00

Regression analysis on retail building energy consumption in the EHA sample [21] estimated electric demand at 4.78 British thermal units per square foot heating degree days, plus or minus 1.95 British thermal units per square foot heating degree days at a 95% confidence level. The electrical space heating demand for retail establishments less than 50,000 square feet, 50,000 to 100,000 square feet, and over 100,000 square feet were found not to be significantly different.

In volume 13 of the AQMP Guidelines [16], the EPA has estimated the average heating requirement of commercial-institutional structures as follows:

Floor Area (10^3 sq.ft.)	Heating Requirement (10^6 Btu/ht.d.d.)
0-20	1.53
20-50	1.80
50-100	2.24
100+	3.07

Taking the midpoint of each floor area range (i.e. 10,35,75,and, say 150), the heating requirement in units of British thermal units per square foot heating degree day can be estimated:

Floor Area (10^3 sq.ft.)	Heating Requirement (Btu/sq.ft.-ht.d.d.)
0-20	153
20-50	51
50-100	29
100+	20

These are so much higher than the FEA, EHA, and the Georgia Power Company estimates (of electric space heat energy demand) that we question their credibility. It is possible that the EPA values include air conditioning and process energy demand.

The mean of the four FEA electric estimates is 4.4 while the EHA estimate is slightly higher at 4.8. There is little basis on which to select either one, so we have elected to use the average of the four FEA estimates, the EHA estimate, and the Georgia Power estimate. This is approximately 4.5 British thermal units per square foot per heating degree days for electric space heat. Gas and oil demand indices were selected in a corresponding manner.

b. Air Conditioning

The EHA sample regression analysis yielded an estimate of 8.87 British thermal units per square foot cooling degree day for air conditioning energy consumption. This is substantially lower than the FEA estimates shown in Table 3-12.

As the EHA estimate is lower than the estimates of air conditioning energy demand in single family structures, we have chosen to discount it and, have instead, elected to use the average of the FEA regional estimates, 17.8 British thermal units per square foot cooling degree day.

c. Process Energy Consumption

The FEA Project Independence estimates of process demand is shown below; in units of British thermal units per square foot per year.

Lighting	27,200
Auxiliary Equipment	12,200
Appliances	6,800
Hot Water:	
Electricity	1,700
Gas	2,400
Oil	3,400
Refrigeration	30,400
Total Process	78,000 - 80,000

This compares well with the estimate of process energy demand derived from the EHA sample, 77793 British thermal units per square foot per year. We have elected to use the FEA estimates; energy demand in retail establishments is summarized in Table 3-13.

2. Office Buildings

The FEA Project Independence Study [12] estimated the energy demand of a typical office building in each of four regions. The typical building was defined to be a 40,000 square foot, three story building. The estimated energy demand for this type of structure is shown in Table 3-14, together with the energy consumption per square foot degree day indices implicit in these estimates.

Regression analysis of data supplied by the Building Owner's and Managers Association (BOMA) yielded:*

$$\frac{\text{Btu}}{\text{sq.ft.}} = 95{,}468 + 6.6 * \text{ht.d.d.} + 5.2 * \text{cl.d.d.}$$

While regression analysis of the EHA sample yielded

$$\frac{\text{Btu}}{\text{sq.ft.}} = 76{,}155 + 3.9 * \text{ht.d.d.} + 2.9 * \text{cl.d.d.}$$

Analysis of both the BOMA and EHA samples showed no significant differences in energy consumption in buildings of various size classes (i.e., less than 50,000 square feet, 50,000 to 100,000 square feet, and over 100,000 square feet of floor area.

The BOMA sample consists of 74.9 X 10^6 square feet of office building. In the FEA study [12], Arthur D. Little estimated the national inventory of office buildings at 3,380 X 10^6 square feet. Accordingly, the BOMA sample represents approximately a 2 percent sample of the population. Despite the low R^2 on the BOMA regression, it should be a better predictor of total energy consumption in office buildings than the FEA engineering estimates or the EHA sample (which is a smaller sample, .07 percent, and only all electric buildings).

---

*A detailed discussion of the regression analysis of the BOMA data can be found in Appendix B.

TABLE 3-13

RETAIL ESTABLISHMENT ENERGY CONSUMPTION

Activity	Energy Consumption per Measure	Measure
Space heat:		
electricity	4.5	sq.ft.•ht.d.d.
gas	9.8	sq.ft.•ht.d.d.
oil	11.0	sq.ft.•ht.d.d.
Air Conditioning, Electricity	17.8	sq.ft.•cl.d.d.
Hot Water:		
electricity	1,700	sq.ft.•year
gas	2,400	sq.ft.•year
oil	3,400	sq.ft.•year
Lighting	27,200	sq.ft.•year
Auxiliary Equipment	12,200	sq.ft.•year
Appliances (other than refrigeration)	6,800	sq.ft.•year
Refrigeration	30,400	sq.ft.•year

TABLE 3-14

FEA ESTIMATE OF OFFICE BUILDING ENERGY DEMAND

		Space Heating			Air Conditioning
		Electricity	Gas	Oil	Electricity
Demand:	MBtu/sq.ft.-yr.				
	North east	44	96	113	10.9
	North central	51	113	113	10.9
	South	24	59	71	25.5
	West	25	61	72	16.0
Demand:	Btu/sq.ft.-d.d.				
	North east	8.15	17.78	20.93	18.2
	North central	8.23	18.23	18.23	21.8
	South	8.57	21.07	25.3	12.8
	West	6.58	16.05	18.95	10.0

Process Use:			
	Lighting	25,500	Btu/sq.ft.·year
	Auxiliary Equipment	7,500	Btu/sq.ft.·year
	Appliances	6,100	Btu/sq.ft.·year
	Hot Water:		Btu/sq.ft.·year
	Electricity	3,400	Btu/sq.ft.·year
	Gas	4,800	Btu/sq.ft.·year
	Oil	6,800	Btu/sq.ft.·year
	Data Processing Equipment	710	Btu/sq.ft.·year
	Total Process	43,210-46,610	Btu/sq.ft.·year

Conversely, the FEA estimates are probably better indicators of the relative demands due to space heating, air conditioning, and process use. While the BOMA regression is the best estimate of the variation in energy consumption per square foot due to variation in heating and cooling degree days, the separate terms in the regression should not be strictly construed as process, space heating, and air conditioning demand. The constant term in the BOMA regression reflects the portion of space heating and air conditioning demand that was constant in the regression.

The ability to distinguish among the three components of energy demand is important if they are supplied by different fuels. The percentage of the total energy demand in the BOMA sample met by each fuel type is tabulated below:

Energy Source	Percentage of Total Energy Supply
Electricity	64%
Steam	18%
Gas	12%
Oil	6%
Coal and Chilled Water	Negligible

Given the distribution, it is apparent that it is not critical to distinguish among the three components of energy consumption. Accordingly, we have elected to use the BOMA regression analysis coefficients for the office building energy consumption factors. These are summarized in Table 3-15.

3. Warehouse and Wholesaling Establishments

Explicit data on energy consumption in warehousing and wholesaling establishments are very limited. The only data available to this study are space heating comsumption reported in the 1958 ASHRAE Handbook [29], viz.,

TABLE 3-15

OFFICE BUILDING ENERGY CONSUMPTION

Activity	Btu per measure	Measure
Space heating		
Electricity, Steam	6.6	Square foot·heating degree day
Gas	9.4	Square foot·heating degree day
Oil	11.0	Square foot·heating degree day
Air Conditioning		
Electricity, Steam	5.2	Square foot·cooling degree day
Gas	7.4	Square foot·cooling degree day
Oil	8.6	Square foot·cooling degree day
Process	95,468	Square foot·year

Building Type	Sample Size	Space heat, Btu/cu.ft.-ht.d.d.
Warehouses	24	0.459
Stores	73	0.624
Department Stores	63	0.385

Assuming a fifteen foot ceiling height for department stores and warehouses, and a ten foot ceiling height for other stores, the energy consumption per square foot heating degree day would be:

Building Type	Space heating, Btu/sq.ft.-ht.d.d.
Warehouses	5.78
Stores	6.24
Department Stores	6.89

This tends to indicate that warehouse space heating demand is approximately the same as retail establishments.

The FEA study [12] assumed that energy consumption in wholesaling and warehousing buildings to be the same as retail establishments.

For lack of other data, we have been forced to follow their precedent and make the same assumption. The 1958 ASHRAE data indicates that this assumption is reasonable.

4. Hotels, Motels and Dormatories and Clubs

This category includes all non-housekeeping residential buildings. Two data sources were appropriate to the requirements of this study. The first, the 1958 ASHRAE Handbook [24], indicated a space heating demand of 0.99 British thermal units per cubic feet heating degree days for hotels and clubs. At a nine foot ceiling height,* this would be 9.0 British thermal units per square foot heating degree days.

The second source is the regression analysis of the EHA sample, viz.,

Btu/sq.ft. = 42172 + 5.63 ht.d.d. + 1.6 cl.d.d.

One can infer from the 1958 ASHRAE value that the 5.63 coefficient does not include all space heating energy consumption, as was the case in the BOMA office building regression.

We have elected to use the EHA regression coefficients as the energy requirement factors for this category. Gas and oil consumption is estimated by utilization efficiencies of, respectively, .7 and .6. These factors are summarized in Table 3-16.

5. Hospitals

The FEA Project Independence Study [12] estimated the energy demand of a typical hospital facility in each of four regions. The typical establishment was defined to be a 60,000 square foot, four story hospital. The estimated energy demand for this type of structure is shown in Table 3-17, along with the energy consumption per square foot degree day implicit in these estimates.

Regression analysis of the EHA sample yielded:

Btu/sq.ft.·year 90486 + 8.33*ht.d.d. + 8.39*cl.d.d.

a. Space Heating

The EHA coefficient substantiates the FEA engineering estimates.

---

*The average ceiling height for hotels, motels, and dormitories in the EHA sample was 9 feet.

TABLE 3-16

NON-HOUSEKEEPING RESIDENTIAL ENERGY CONSUMPTION

Activity	Btu/Measure	Measure
Space heating		
Electricity	5.63	Square foot•heating degree day
Gas	8.04	Square foot•heating degree day
Oil	9.38	Square foot•heating degree day
Air Conditioning		
Electricity	1.60	Square foot•cooling degree day
Gas	2.29	Square foot•cooling degree day
Oil	2.67	Square foot•cooling degree day
Process	42,172	Square foot•year

TABLE 3-17

FEA ESTIMATES OF HOSPITAL ENERGY DEMAND

		Space Heating Electricity	Gas	Oil	Air Conditioning Electricity
Demand:	MBtu/sq.ft. year				
	North east	46	103	122	13.6
	North Centrla	54	121	143	13.6
	South	19	51	61	34.0
	West	25	63	76	21.1
Demand:	Btu/sq.ft. d.d.				
	North east	8.52	19.07	22.59	22.67
	North Central	8.71	19.52	23.06	27.20
	South	6.79	18.21	21.79	17.00
	West	6.58	16.58	20.00	13.19
	Mean	7.65	18.35	21.86	20.02

Process:	Lighting	51,000	
	Auxiliary Equipment	59,600	
	Appliances	20,300	
	Hot Water:		
	Electric	17,000	
	Gas	24,000	
	Oil	34,000	
	Total Process	147,900 - 164,900	Btu/sq.ft.·year

b. Air Conditioning

The EHA coefficient indicates an air conditioning energy demand 40% of the FEA estimates.

c. Process

The EHA coefficient indicates a process energy requirement of 60% of the FEA estimate. Hittman Associates have estimated the process energy demand at a characteristic hospital to be 137,400 British thermal units per square feet per year [25]. This tends to support the FEA estimate over the EHA coefficient.

We have elected to use the average of the FEA regional estimates (as shown in Table 3-17) for the energy requirement factors. This decision is based on the relatively low values of the EHA air conditioning and process requirement coefficients when compared with other building categories in the commercial-institutional sector. In addition, we note the confirmation of the FEA data by the Hittman estimate.

6. Cultural Buildings

The category includes libraries, museums, and other miscellaneous buildings characterized as having longer than average operating hours*.

The only source of data for this building category is the regression analysis of the EHA sample, viz.,

$$\text{Btu/sq.ft.} = 40{,}944 + (6.31 * \text{ht.d.d.}) + (2.01 * \text{cl.d.d.})$$

---

*In the EHA sample, the mean hours per week a building was open is as follows:

Office Building	61
Retail Establishments	63
Hospitals	130
Cultural Buildings	96
Schools	65
Hotels	168
Churches	49

These values are summarized in Table 3-18, along with estimates for natural gas and fuel oil based on utilization efficiencies of respectively, .7 and .6.

7. Churches

This category includes churches and other miscellaneous buildings characterized as having shorter than average operating hours.

The regression analysis of the EHA sample yielded;

Btu/sq.ft.= 14,166 +(10.0*ht.d.d.) + (12.83*cl.d.d.)

This is supported by data in the 1958 ASHRAE Handbook [24], which reported a space heating demand in churches of 0.532 British thermal units per cubic feet heating degree days. At the 16 foot ceiling height in the EHA sample, this would be 8.5 British thermal units per square foot heating degree days. While this is lower than the EHA estimate of 10.0, we would expect that the ASHRAE data includes many older churches with ceiling heights considerably higher than 16 feet.

Energy consumption in churches is summarized in Table 3-19. Gas and oil factors were computed with .7 and .6 utilization efficiencies.

8. Schools

The FEA Project Independence study [12] estimated the energy consumption of a typical school building. The typical building was defined to be a 40,000 square foot, single story building. The energy demand of this building in each of four regions is shown in Table 3-20, along with the per square foot degree day energy consumption implicit in these estimates.

The regression analysis of the EHA sample yielded:

Btu/sq.ft.= 24,320 + (5.63*ht.d.d.) + (1.60*cl.d.d.)

TABLE 3-18

CULTURAL BUILDING ENERGY CONSUMPTION

Activity	Btu/Measure	Measure
Space heating		
Electricity	6.31	Square foot•heating degree day
Gas	9.01	Square foot•heating degree day
Oil	10.52	Square foot•heating degree day
Air Conditioning		
Electricity	2.01	Square foot•cooling degree day
Gas	2.87	Square foot•cooling degree day
Oil	3.35	Square foot•cooling degree day
Process	40,944	Square foot•year

TABLE 3-19

CHURCH BUILDING ENERGY CONSUMPTION

Activity	Btu/Measure	Measure
Space Heating		
Electricity	10.00	Square foot•heating degree day
Gas	14.29	Square foot•heating degree day
Oil	16.67	Square foot•heating degree day
Air Conditioning		
Electricity	12.83	Square foot•cooling degree day
Gas	18.33	Square foot•cooling degree day
Oil	21.38	Square foot•cooling degree day
Process	14,166	Square foot•year

TABLE 3-20

FEA ESTIMATES OF SCHOOL BUILDING ENERGY DEMAND

		Space Heating Electricity	Gas	Oil	Air Conditioning Electricity
Demand:	MBtu/sq.ft.-year				
	North east	40	85	100	9.2
	North Central	46	99	117	9.2
	South	18	44	52	20.4
	West	23	54	64	11.9
Demand:	Btu/sq.ft.-d.d.				
	North east	7.41	15.74	18.52	15.33
	North Central	7.42	15.97	18.87	18.40
	South	6.43	15.71	18.57	10.20
	West	6.05	14.21	16.84	7.44
	Mean	6.83	15.41	18.20	12.84

Process:	Lighting	22,100	Btu/sq.ft.•year
	Auxiliary Equipment	11,200	Btu/sq.ft.•year
	Appliances	5,100	Btu/sq/ft.•year
	Hot Water		Btu/sq.ft.•year
	Electricity	3,400	Btu/sq.ft.•year
	Gas	4,800	Btu/sq.ft.•year
	Oil	6,800	Btu/sq.ft.•year
	Total Process	41,800 - 45,200	Btu/sq.ft.•year

The constant term, the coefficient of heating degree days, and the coefficient of cooling degree days are all less than the respective FEA estimates.

Several other data sources on measured energy consumption in schools is summarized in Table 3-21. In general, they are smaller than and thus tend to support the 24,320 British thermal units per square foot per year estimate of process use from the EHA sample over the FEA estimate of 42,000-45,000. The electric space heating indices in Table 3-21 also support the EHA estimate over the FEA estimate.

There is considerable difference between the FEA estimate and the estimate from the EHA sample of air conditioning energy demand. There is little additional data on which way to resolve this conflict. The FEA estimate does assume full operation of the school in the summer, while the estimate from the EHA estimate may reflect a more accurate limited operation of the school buildings. For this reason, and because the FEA estimate of the other two components of energy consumption were judged too high, we have elected to use the estimates derived from the EHA data. These data are summarized in Table 3-22, along with estimates for gas and oil heated buildings.

TABLE 3-21

OTHER AVAILABLE DATA ON MEASURED ENERGY CONSUMPTION IN SCHOOLS

Robert Dillard [26]	5 Electrically heated schools - New England	
	Heating and ventilation	4.207 Btu/sq.ft.-d.d.
	Process	12,491 Btu/sq.ft.
Robert Dillard [27]	15 Fossil Fuel heated schools - New England	
	Heating	31.56 Btu/sq.ft.-d.d.
	Process	14,894 Btu/sq.ft.
Empire District Electric Company [28]	22 Electrically heated schools - Midwest	
	Heating and hot water	5.460 Btu/sq.ft.-d.d.
	Process	9,653 Btu/sq.ft.
Empire District Electric Company [28]	52 Fossil fuel heated schools - Midwest	
	Heating and hot water	20.13 Btu/sq.ft.-d.d.
	Process	8,526 Btu/sq.ft.
1958 ASHRAE Handbook [29]	8 Steam heated schools	
	Heating	0.592 Btu/cu.ft.-d.d.*
	(at 10' ceilings:	5.92 Btu/sq.ft.-d.d.)
Oak Ridge National Laboratory [24]	Estimated steam consumption,	
	Heating	7.106 Btu/sq.ft.-d.d.

*At 1,000 Btu/lb.

TABLE 3-22

SCHOOL BUILDING ENERGY CONSUMPTION

Activity	Btu/Measure	Measure
Space Heating		
Electricity	5.63	Square foot·heating degree day
Gas	8.04	Square foot·heating degree day
Oil	9.38	Square foot·heating degree day
Air Conditioning		
Electricity	1.6	Square foot·cooling degree day
Gas	2.29	Square foot·cooling degree day
Oil	2.67	Square foot·cooling degree day
Process	24,320	Square foot·year

C. INDUSTRIAL

The estimation and use of land use based emission factors for the industrial sector presents severe problems. The potential variation in emission per square foot of floor area (or, at least, per acre of land) is documented in reference 6. The estimation of emissions from a single industrial source apparently can be much more inaccurate in percentage terms than, for example, the estimation of emissions from a residential source.

Such behavior, however, is typical to some degree of any emission factor. Also, it is our belief that this variation has been dampened by basing the emission factors on building floor area instead of land area. Finally, as noted in Chapter I, the estimation of total emissions in a region will approach the true population value.

Our approach to the development of land use based emission factors in the industrial sector differs from that used in the residential and commercial-institutional sectors. Actual observations of fuel consumption (or emissions) and building floor area are not readily available. Furthermore, given the assumed variation in the emissions per building floor area, a relatively large sample would be needed for our accurate estimate of the mean.

Consequently, our approach is based on separate observations of building floor area per employee, fuel consumption per employee, and emissions per fuel consumption, viz.,

$$\frac{Q_i}{A_j} = \Sigma_K \frac{Q_i}{F_k} \frac{F_k}{E_j} \frac{E_j}{A_j}$$

where: Q_i = emissions of pollutant i
A_j = floor area, industrial category j
F_k = fuel, type k
E_j = employment, industrial category j

(Q_i/F_k) is available from EPA publication AP-42 [7]. Observations of (F_k/E_j) are available from the Census of Manufacturers [30], disagregated by state. (E_j/A_j) is available in reference 31.

The quantity is summed over fuel type, k, and as such assumes the relative fuel choices within an industrial category j (SIC code j). Note that the results of this process is an emission factor disaggregated by SIC code; an aggregated industrial emission factor could be constructed for a small area by compiling an average weighted by small area employment in each SIC category.

It is important to note that process emissions are not considered in this approach. Argonne [6] has demonstrated the inadequacy of industrial land use based emission factors when applied to a point source inventory dominated by process particulate matter emissions. As our approach only considers fuel combustion emissions, it is more akin to the typical treatment of area source emissions in an emissions survey [32]. It can reasonably be extended to point source emissions in areas where process emissions are not significant.

The development of an average national industrial land use based emission factor is demonstrated in Tables 3-23 through 3-27. These tables implicitly assume the national fuel choice proportions for each two digit SIC code. Therefore, these tables will be inaccurate in regions of the Country that are more or less dependent on coal or natural gas than the average of the nation. Accordingly, it is suggested that the state-level fuel choice proportions [30] be used instead of the national values used in Tables 3-24

Table 3-23 presents the mean building floor area per employee in each SIC category, as presented in reference 31.

Table 3-24 presents the mean consumption per employee of each fuel type, developed from references 30 and 33.

Table 3-25, the product of Tables 3-23 and 3-24, presents the mean consumption per floor area by fuel type in each SIC category.

Table 3-26 restates the emission factors found in reference 7.

Table 2-13 presents the product of the emission factors in Table 3-26 and the mean consumption per floor area in Table 3-25.

TABLE 3-23

ESTIMATED BUILDING FLOOR AREA PER EMPLOYEE BY TWO DIGIT 1967 STANDARD INDUSTRIAL CLASSIFICATION CODE

SIC Code	Name	Square Feet Per Employee
19	Ordnance and Accessories	206
20	Food and Kindred Products	598
21	Tobacco Manufacturers	282
22	Textile Mill Products	403
23	Apparel	263
24	Lumber and wood products	796
25	Furniture and Fixtures	628
26	Paper and Allied Products	649
27	Printing, Publishing and Allied Industries	363
28	Chemicals and Allied Products	649
29	Petroleum Refining and Related Industries	394
30	Rubber and Miscellaneous Plastics	604
31	Leather and Leather Products	345
32	Stone Clay and Glass Products	545
33	Primary Metal Industries	352
34	Fabricated Metal Products	476
35	Machinery	418
36	Electrical Machinery	255
37	Transportation Equipment	313
38	Instruments	253
39	Miscellaneous Manufacturing Industries	426

TABLE 3-24

MEAN 1971 FUEL CONSUMPTION PER EMPLOYEE BY 1967 STANDARD INDUSTRIAL CLASSIFICATION CODE

	Distillate Oil barrels per employee	Residual Oil barrels per employee	Coal tons per employee	Gas Mcf per employee	Electricity 10^3 kWh per employee
20	7.04	6.38	2.88	.31	22.91
21	3.00	7.49	2.58	.06	13.55
22	5.13	7.23	1.70	.11	27.52
23	.72	.16	.11	.01	4.18
24	10.38	1.64	.35	.13	17.57
25	1.33	.83	.52	.04	9.05
26	15.97	73.59	14.94	.75	55.39
27	.87	.40	.02	.04	9.15
28	17.44	22.45	.22	1.68	117.37
29	22.94	75.75	2.54	9.35	167.66
30	5.34	4.37	2.29	.14	30.17
31	2.53	2.12	.42	.03	6.24
32	19.10	14.44	16.66	1.21	42.65
33	13.66	17.93	8.09	.94	104.68
34	2.31	1.48	.51	.12	15.87
35	1.82	1.59	.70	.09	12.80
36	1.64	1.52	.41	.06	14.21
37	2.01	2.16	1.61	.09	16.95
38	1.59	3.05	1.83	.04	9.50
39 and 19	2.55	2.24	.20	.06	10.65

TABLE 3-25

MEAN 1971 FUEL CONSUMPTION FOR HEAT AND POWER PER BUILDING FLOOR AREA, BY TWO DIGIT 1967 STANDARD INDUSTRIAL CLASSIFICATION CODE

	Distillate Oil (gals/sq.ft.)	Residual Oil (gals/sq.ft.)	Coal (lbs/sq.ft.)	Gas (cf/sq.ft.)	Electricity (kWh/sq.ft.)
20	0.49	.45	9.63	.52	38.32
21	.45	1.12	18.32	.21	48.03
22	.53	.75	8.46	.27	68.28
23	.1	.03	.85	.04	15.89
24	.55	.09	.87	.17	22.08
25	.09	.06	1.65	.07	14.41
26	1.03	4.76	46.03	1.16	85.34
27	.10	.05	.09	.10	25.20
28	1.13	1.45	.69	2.59	180.84
29	2.45	8.08	12.88	23.74	425.53
30	.37	.30	7.58	.23	49.95
31	.31	.26	2.45	.09	18.09
32	1.47	1.11	61.15	2.22	78.27
33	1.63	2.14	45.98	2.68	297.40
34	.20	.13	2.13	.26	33.34
35	.18	.16	3.33	.21	30.63
36	.28	.25	3.24	.25	55.71
37	.27	.29	10.29	.28	54.16
38	.26	.51	14.43	.16	37.56
19 & 30	.32	.28	1.18	.18	31.23

TABLE 3-26

INDUSTRIAL EMISSION FACTORS

	Units	PM	SO_x	CO	HC	NO_x
Bituminous Coal	lb/ton	13A	385	2	1	15
Natural Gas	lb/10^6 cf	10	.6	17	3	180
Distillate Oil	lb/1000 gal.	15	1445	4	3	60
Residual Oil	lb/1000 gal.	23	1575	4	3	60

IV. GENERATION OF LAND USE BASED EMISSION FACTORS

As discussed in Chapter I, the land use based emission factor is a product of the "standard" emission factor and the activity factor, i.e., energy consumption per unit floor area.

The "standard" emission factors used in this study were those compiled in reference 7 and restated in Table 4-1 in terms of British thermal units of fuel input. Heat contents of selected fuels are shown in Table 4-2. One-hundred and fifty thousand (150,000) British thermal units per gallon were used for residual oil. Residential use of fuel oil was assumed to be supplied by distillate oils; commercial-institutional use of fuel oil was assumed to be supplied by residual oils.

The product of the activity factors developed in Chapter III and the emission factors presented in Table 4-1 is the land use based emission factors. These factors have been computed and are summarized in Chapter II.

The secondary emissions, i.e., the emissions at the local power plant, depends both on the electricity demand in the region under consideration and the nature of the local power plant supplying this demand. It is advisable to contact the local utility to determine the emissions per kWh generated. As a default value, typical plant efficiencies* and transmission losses** have been employed to generate Table 4-3, typical emissions at electric utilities in terms of kilowatt-hours consumed by ultimate customers.

It is useful to note at this point what has not been included in the emission factors summarized in Chapter II. Table 4-4 presents the percentage of the national emission loading by source category. As mentioned in Chapter III, Section C, process emissions were not included in the industrial land use emission factors. This would have the effect of understating particulate

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* 10,250 Btu per kWh generated for coal plants,
10,800 Btu per kWh generated for oil and gas plants [34]

**10% of kWh consumed are transmission losses [35]

TABLE 4-1

SELECTED EMISSION FACTORS, LBS PER BTU

	PM	SO_x	CO	HC	NO_x
Residential					
oil	7.14×10^{-8}	$1.03 \times 10^{-6}S$	3.57×10^{-8}	2.14×10^{-8}	8.57×10^{-8}
gas	1.00×10^{-8}	6.00×10^{-10}	2.00×10^{-8}	8.00×10^{-9}	1.00×10^{-7}
Commercial-Institutional					
oil	1.53×10^{-7}	$1.06 \times 10^{-6}S$	2.67×10^{-8}	3.00×10^{-6}	4.00×10^{-7}
gas	1.00×10^{-8}	6.00×10^{-10}	2.00×10^{-8}	8.00×10^{-9}	1.00×10^{-7}

TABLE 4-2

ENERGY CONTENTS OF SELECTED FUELS

Fuel	Heating Value
Coal	
anthracite	13,900 Btu/lb.
bituminous	14,000 Btu/lb.
sub-bituminous	12,600 Btu/lb.
lignite	11,000 Btu/lb.
Heavy Fuel Oils and Middle Distillates	
kerosene	134,000 Btu/gallon
No. 2 burner fuel oil	140,000 Btu/gallon
No. 4 heavy fuel oil	144,000 Btu/gallon
No. 5 heavy fuel oil	150,000 Btu/gallon
No. 6 heavy fuel oil, 2.7% sulfur	152,000 Btu/gallon
No. 6 heavy fuel oil, 0.3% sulfur	143,800 Btu/gallon
Gas	
natural	1,000 Btu/cu.ft.
liquefied butane	103,300 Btu/gallon
liquefied propane	91,600 Btu/gallon

TABLE 4-3

TYPICAL EMISSION FACTORS FOR ELECTRIC UTILITIES

	lbs. emissions per kWh sold to customer				
	PM	SO_x	CO	HC	NO_x
coal	5.23×10^{-3}	$1.53 \times 10^{-2}S$	4.03×10^{-4}	1.21×10^{-4}	2.21×10^{-2}
oil	6.34×10^{-3}	$1.26 \times 10^{-2}S$	2.38×10^{-4}	1.58×10^{-4}	8.32×10^{-3}
gas	1.19×10^{-4}	7.13×10^{-6}	2.02×10^{-4}	1.19×10^{-5}	8.32×10^{-3}

TABLE 4-4

PERCENTAGE OF NATIONAL EMISSIONS LOADINGS BY SOURCE CATEGORY

	PM	SO_x	NO_x	HC	CO
Fuel Combustion	52%	85%	59%	1%	1%
Industrial Process	45%	14%	3%	53%	32%
Solid Waste Disposal	1%	0%	2%	5%	5%
Land Vehicles	1%	1%	35%	34%	60%
Other	1%	0%	1%	8%	2%

Source: Reference 36

and hydrocarbon emissions in regions characterized predominantly by industrial process emissions*.

In addition, note that solid waste disposal and solvent evaporation have been ignored in developing the land use based emission factors in this report. Considering the accuracy of these factors and Table 4-4, the impact of this omission would appear to be negligible.

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*Table 4-4 probably overstates the impact of ignoring process emissions on particulate matter emissions, since fugitive dust sources are largely unaccounted for in reference 36.

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APPENDIX A

CALCULATION OF RESIDENTIAL AIR CONDITIONER OPERATING HOURS

Abstracted From Reference 17

7

Compressor-operating hours were calculated by using the National Bureau of Standard Load Determination Computer Programmer. Calcualations were performed using hour-by-hour weather tapes for one year in 10 cities. To generalize these results to other locations, the results are assumed a function of latitude and weather variables. This allowed the generation of the con tour map given in Figure 1-3. The rest of this appendix outlines the methodology used by Oak Ridge National Laboratory.

To estimate the compressor operating hours for locations not calculated by NBSLD, a series of multivariable regression relationships was used. Annual cooling degree hours (70°F base) are obtained as a function of latitude and dry-bulb temperatures that are exceeded 1 and 5% of the time during the months of June through September for the 10 cities. Air conditioner capacity requirements are found as a function of latitude, dry-and wet-bulb temperatures that are exceeded 1% of the time during the summer months, and the difference between the average maximum and average minimum temperatures during the warmest month.

Annual cooling requirements are assumed a function of the predicted cooling degree hours (sensible load), the latitude (solar load), and the square of the difference between the 5% exceeded wet bulb temperature and 65°F (latent infiltration load; if negative, zero is assumed). For the assumed indoor conditions (78°F, 50% relative humidity), no latent infiltration load occurs if the outdoor wet-bulb temperature is below 65°F. For cooling requirements when natural ventilation is also used, an additional wind variable is included. The coincident wind variable for Ref. 37 is used as a proxy for the wind intensity.

Average values of the independent variables required to predict cooling degree hours, cooling capacity and annual cooling requirements are given in Ref. 37 for over 700 cities. The data for each city are used to calculate the compressor-operating hours (cooling requirement divided by capacity) and plot the contour maps in Figure 1-3. Table A-1 compares the predictions with the NBSLD calculations for the cities and years investigated.

TABLE A-1

COMPARISON OF NBSLD CALCULATIONS AND PREDICTION EQUATIONS FOR ANNUAL COMPRESSOR-OPERATING HOURS

City (year)	NBSLD	Predictions	
Atlanta (1955	1521	1577	(3.7)
Chicago (1955)	727	868	(19.5)
Dallas (1955)	2003	1979	(1.2)
Miami (1955)	2901	2971	(2.4)
Minneapolis (1949)	590	462	(21.6)
New Orleans (1955)	2305	2157	(6.4)
New York[b] (1955)	755	765	(1.3)
Phoenix (1955)	2122	2102	(.9)
San Diego (1955)	592	583	(1.4)
Topeka (1959)	932	1023	(9.7)

[b] Weather tape is for Kennedy Airport.

APPENDIX B

REGRESSION ANALYSIS OF BUILDING OWNER'S AND MANAGERS ASSOCIATION (BOMA) SAMPLE

The Building Owners and Managers Association International of Chicago, Illinois publishes annually an Office Building Experience Exchange Report which summarizes office building operating expenses and income as reported by their members [35]. With their assistance, Walden Research was able to construct a sample of office energy consumption variables as summarized in Table B-1. The data were such that buildings were not identified; thus, the operations of individual buildings were not disclosed. All data were annual.

The basic specification of the analysis was;

$$\text{Energy Consumption per square foot} = \alpha + (\beta_1 * \text{ht.d.d.}) + (\beta_2 * \text{cl.d.d.})$$

The energy consumption of a building can be categorized into three components: process, space heating, and space cooling. Theoretically, the process consumption should be a constant, while space heating and space cooling are functions of climate, here specified as heating and cooling degree days. The principal reason for this specification, and not separate analyses of the three components was that the BOMA data did not distinguish between the three components.

Before this regression could be performed, the various efficiencies of utilization had to be accounted for. As a first approximation, we assumed 1.0 for electricity, 0.7 for gas, 0.6 for oil, 0.8 for steam, and 0.5 for other fuels. Thus, the total energy demand per square foot of each office building was computed as follows:

$$\text{ENERGY} = \text{FUEL } 1 + .7 * \text{FUEL } 2 + .6 * \text{FUEL } 3 + .8 * \text{FUEL } 4 + .5 * \text{FUEL } 5$$

Regression analysis then yielded, with standard errors in parenthesis;

$$\begin{array}{llll} \text{ENERGY} = 95467 & + \ 6.619 \text{ ht.d.d.} & + \ 5.150 \text{ cl.d.d.} \\ & \quad (3.874) & \quad (8.848) \\ & \quad F=2.92 & \quad F=.339 \end{array}$$

$$R^2 = .011 \quad \text{St. Error} = 101466 \quad F\ (2,273) = 1.53$$

The result of this regression was very disappointing; only one percent of the variance in office building energy consumption per square foot could be explained by heating and cooling degree days.

TABLE B-1

VARIABLE NAMES IN BOMA SAMPLE

AGE	Age of Building
HEIGHT	Height of Building, number of stories
OCCUP	Occupancy Rate, percentage
AREA	Building Floor Area, square feet
FUEL1	Electricity Consumption per square foot, Btu/sq.ft.
FUEL2	Gas Consumption per square foot, Btu/sq.ft.
FUEL3	Oil Consumption per square foot, Btu/sq.ft.
FUEL4	Steam Consumption per square foot, Btu/sq.ft.
FUEL5	Other Fuels (principally coal and chilled water) Btu/sq.ft.
FUELSUM	Total Energy Consumption per square foot, Btu/sq.ft.
HTDEGDAY	Heating Degree Days,
CLDEGDAY	Cooling Degree Days
HRSOV80	Hours Temperature was over 80°
COOLHRS	Compressor Operating Hours (from reference 17)

The use of operating hours instead of cooling degree days was not much different.

$$ENERGY = 89823 + \underset{\substack{(3.895)\\ F=3.58}}{(7.371*ht.d.d.)} + \underset{\substack{(12.14)\\ F=.866}}{(11.29*cl.d.d.)}$$

$R^2 = .013$ Std. Error = 101,367 $F = (2,273) = 1.79$

To investigate the possible influence of incorrect utilization efficiencies or size of building, seven zero-one dummy variables were constructed, viz.,

DUM 50	'1'	if AREA is less than 50,000
DUM 100	'1'	if AREA is greater than 100,000
DUM ELEC	'1'	if FUEL is non zero
DUM GAS	'1'	if FUEL is non zero
DUM OIL	'1'	if FUEL is non zero
DUM STEAM	'1'	if FUEL is non zero
DUM OTHER	'1'	if FUEL is non zero

In stepwise regression analysis, if either of the first two variables were significant, one would suspect important differences in energy consumption per square foot in buildings in different size classes. If any of the last five dummies were important, one would suspect that the utilization efficiency for that fuel was either too large or too small.

Stepwise regression analysis on these dummies and all the other available variables is shown in Table B-2. A 95% confidence level was used (i.e., t = 1.96, F = 3.84). Interestingly, the age of a building was the most important variable, with energy consumption increasing in more recently constructed buildings. DUM ELEC was positive and significant, indicating that the utilization efficiency of electricity was higher than 1.0 (perhaps due to the use of heat pumps) or that the other utilization efficiencies were too high. However, the important point of this regression is that none of the variables considered are able to explain very much of the variance in energy consumption per square foot. The R^2 is only .06.

TABLE B-2

STEPWISE ANALYSIS OF BOMA SAMPLE

```
DEPENDENT VARIABLE..    ENERGY



MULTIPLE R              .25185                          DF         F
R SQUARE                .06343                           3     6.14023
ADJUSTED R SQUARE       .05657                         272
STANDARD ERROR   98924.68013



----------------- VARIABLES IN THE EQUATION -----------------

VARIABLE               B           BETA     STD ERROR B          F

AGE             -818.01489     -.19771      250.86081        10.633
HTDEGDAY           8.74996      .15975        3.33169         6.897
DUMELEC        79767.30718      .13188    35613.17036         5.017
(CONSTANT)     38062.25934



------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE        BETA IN      PARTIAL   TOLERANCE          F

HEIGHT         -.04594      -.04715      .98655         .604
NOBLDG          .01618       .01667      .99457         .075
OCCUP           .10504       .10400      .91820        2.963
AREA           -.10865      -.10860      .93571        3.234
CLDEGDAY        .03776       .03306      .71776         .296
HRSOV80         .07118       .06437      .76579        1.127
COOLHRS         .04269       .03688      .69902         .369
DUM50          -.03602      -.03711      .99404         .374
DUM100          .09432       .09658      .98211        2.552
DUMGAS          .05792       .05971      .99538         .970
DUMOIL          .05275       .05354      .96465         .779
DUMSTEAM        .06799       .06557      .87106        1.170
DUMOTHER       -.10627      -.10968      .99778        3.300
```

Due to the significance of DUM ELEC, subsequent regressions were performed with different utilization efficiencies. No significant change in the coefficients or R^2 was noted.

The sample was then divided into three sub-samples, buildings less than 50,000, between 50,000 and 100,000, and over 100,000 square feet. The comparison of individual regressions on these samples indicated no significant difference in the resulting coefficients. In addition, analysis of variance of the mean energy consumption per square foot also showed no difference between the means of each sample.

Finally, it should be noted that the goal of this analysis was to be able to predict total energy consumption of office buildings, not energy consumption per square foot. It is important then to ask how well energy consumption is predicted by using energy consumption per square foot. An approximate answer to this question is afforded by the regression of energy consumption on area, viz.,

$$\text{Energy in Btu} = .99 \times 10^{10} + 88152 \text{ Area}$$

$R^2 = .51$
(other statistics were not readily available)

One is able to account for slightly over 50% of the variation in total energy consumption per building by area alone.

APPENDIX C

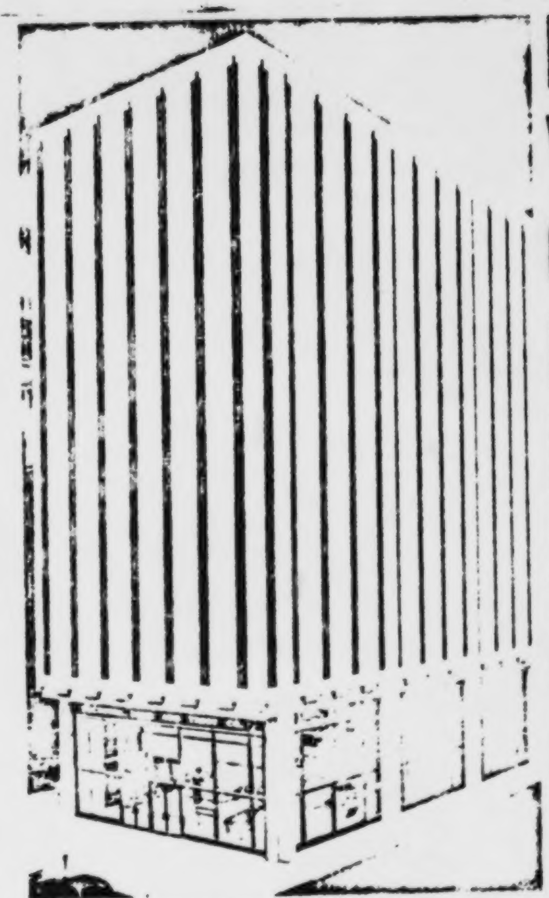
REGRESSION ANALYSIS OF ELECTRIC HEATING ASSOCIATION (EHA) SAMPLE

The Electric Heating Association published a series of case studies of recent all-electric buildings. These case studies reported actual monthly electricity consumption of the building. An example of the EHA case studies is shown in Figure 1.

The monthly electricity consumption data was coded for each building, along with building area, volume, and other design information on the EHA case study. Heating and cooling degree days, hours over 80°, and operating hours were compiled and also coded.

Regression analysis was performed separately for each building category on both monthly and annual data. The results are summarized on Table 4. One immediately notes the substantial differences between the monthly and annual regressions. We believe there are two complimentary reasons for this phenomena. First, the annual data, by summing the monthly data, has lost some of the variance. Secondly, the monthly data is a hybrid time series-cross sectional sample. One traditionally expects a higher R^2 in time series analysis. The monthly data is considered to be more relevant to the goal of this analysis, as it can more adequately differentiate between process, heating, and cooling energy demand.

The commercial, hospital, school, and hotel data in the EHA sample were separately desegregated into building size classes. Separate regressions were then performed on each sub-sample and the results compared (e.g., the coefficients in the regression of commercial electricity consumption per square foot on heating and cooling degree days were compared between separate regressions on buildings less than 50,000 square feet, 50,000-100,000 square feet, and greater than 100,000 square feet). The regressions were not significantly different between the different size classes, i.e., there was not a significant difference in the energy consumption per square foot in buildings of various sizes. It is our opinion that in fact there are significant differences in the population, but these differences are small when compared to the confidence interval of each regression.



Eleven-story Wachovia Building in Raleigh, N.C.

New All-Electric Wachovia Bank, Office Building In Raleigh, N. C., Enhances Downtown Area and Provides Favorable Owning, Operating Costs For Its Owners

THE CASE — The Wachovia Building in Raleigh, North Carolina, an 11-story bank and office building designed by A. G. Odell, Jr., and Associates, architects and engineers of Charlotte, N.C., accomplishes two objectives of good design: it meets the general office needs of the Wachovia Bank and Trust Company and it adds a new and interesting dimension to the city's changing skyline.

Now in its 90th year with 89 offices in 42 communities and resources in excess of $1.4 billion, Wachovia is the largest commercial bank in the Southeast and the 39th largest in the United States (out of some 13,000). In keeping with this impressive record of growth and service, the bank's directors wanted the Raleigh building to be "architecturally interesting, functionally efficient, and capable of future expansion."

THE HISTORY — The resulting building meets these objectives admirably. A pattern of vertical panels of cast stone and marble alternate with dark-tinted glass on the upper seven floors to emphasize the classic simplicity of the structure and

the glass encased public banking area and overlooks the two-story entrance lobbies at either end of the building. Interior spaces include a huge computer center on the fifth floor which operates under carefully controlled temperature and humidity conditions made possible by the building's electric heating/cooling system.

An electric space conditioning system was selected after a feasibility study revealed that it would save between $3,500 and $5,000 a year on owning and operating costs and permit each zone to be controlled independently. Air is distributed through a medium-pressure dual duct system with individual constant-volume mixing boxes for each office and space. The system, which permits simultaneous heating or cooling, utilizes a centrifugal chiller with double-bundle condenser to supply hot and cold water to coils in three air handling units.

Since completion of the building in January, 1965, the electric system has performed beautifully, consulting engineer Edgar C. Jones of the Odell firm reports, operating well within the estimated costs and at the same time meeting all of the requirements of temperature and humidity con-

FIGURE 1 EHA CASE STUDIES

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1 CATEGORY OF STRUCTURE:
Commercial—Office Building

2 GENERAL DESCRIPTION:
Area: 122,800 sq ft
Volume: 1,800,000 cu ft
Number of floors: 11
Number of occupants: 850
Types of rooms: banking lobby, private and general offices, computer room, cafeteria, kitchen, rental suites

3 CONSTRUCTION DETAILS:
Glass: double, solar bronze
Exterior walls: pre-cast concrete panels, 3" glass fiber batts (R-11), plaster board; U-factor: 0.08
Roof and ceilings: mechanical room on roof is unheated but machines generate enough heat gain to minimize heat loss through the roof. U-factor does not apply.
Floors: concrete slab
Gross exposed wall area: 55,158 sq ft
Glass area: 26,592 sq ft

4 ENVIRONMENTAL DESIGN CONDITIONS:
Heating:
Heat loss Btuh: 2,200,000
Normal degree days: 3393
Ventilation requirements: 22,700 cfm
Design conditions: 10F outdoors; 75F indoors
Cooling:
Heat gain Btuh: 6,000,000
Ventilation requirements: 22,700 cfm
Design conditions: 95F dbt, 78F wbt outdoors; 75F, 50% rh indoors

5 LIGHTING:
Levels in footcandles: 35-100
Levels in watts/sq ft: 3-5
Type: fluorescent and incandescent

6 HEATING AND COOLING SYSTEM:
Air is distributed through a medium-pressure dual-duct system with individual constant-volume mixing boxes for each office and space. The heart of the system, which is capable of simultaneously heating and cooling, is a 195-kw centrifugal chiller with double-bundle condenser that supplies both warm and cold water to coils in three air handling units. With this arrangement heat can be transferred from areas requiring cooling for use in other zones. Nine 50-kw immersion heaters in the chilled water return line provide auxiliary heat and five 50-kw elements in the warm water loop are used for emergency. A second chiller, rated at 265 kw, is used for cooling loads only.

7 ELECTRICAL SERVICE:
Type: underground
Voltage: 277/480v, 3 phase, 4 wire, wye
Metering: secondary

8 CONNECTED LOADS:

Heating & Cooling (500 tons)	645 kw
Lighting	370 kw
Cooking	100 kw
Water Heating	36 kw
Snow Melting	210 kw
Other	150 kw
TOTAL	1511 kw

9 INSTALLED COST:*

General Work	$2,657,839	$22.06/sq ft
Electrical	248,400	2.06/sq ft
Mechanical	413,433	3.43/sq ft
Plumbing	92,400	.77/sq ft
TOTALS	$3,412,072	$28.32/sq ft

*Building was completed 1/65

10 HOURS AND METHODS OF OPERATION:
9 a.m. to 5 p.m. five days a week.

11 OPERATING COST:
Period: 12/19/67 to 12/19/68
Actual degree days: 3594
Actual kwh: 4,837,500*
Actual cost: $46,382.80*
Avg. cost per kwh: 0.96 cents*
*For total electrical usage

Billing Date	Degree Days	Demand	kwh	Amount
1/23/68	920	1188	513,000	$ 4,728.20
2/21/68	735	1134	430,500	4,220.60
3/22/68	562	1053	412,500	3,999.20
4/23/68	232	810	388,500	3,515.00
5/22/68	113	1053	370,500	3,747.00
6/21/68	31	891	357,000	3,439.40
7/23/68		945	393,000	3,731.00
8/22/68		864	426,000	3,815.60
9/23/68		891	409,500	3,754.40
10/21/68	36	972	346,500	3,489.80
11/20/68	309	1053	391,500	3,873.20
12/19/68	656	1161	399,000	4,069.40
TOTALS	3594		4,837,500	$46,382.80

12 FEATURES:
Temperatures in all zones can be controlled independently. A temperature sensor in each space is wired into a central control panel located in the basement. Comfort conditions are adjusted at the panel, not within the zones themselves.

13 REASONS FOR INSTALLING ELECTRIC HEAT:
A feasibility study indicated that the annual owning and operating costs for the all-electric system would be from $3,500 to $5,000 less than the costs of equivalent systems using gas and two grades of fuel oil for heating. Because aesthetics was also an important design consideration, the choice was further influenced by the fact that the electric system would not require chimneys or flues.

14 PERSONNEL:
Owner: Wachovia Bank and Trust Co.
Architects and Engineers: A. G. Odell, Jr., and Associates
General Contractor: T. A. Loving Company
Electrical Contractor: A & N Electric Co.
Mechanical Contractor: Albemarle Plumbing & Heating Co.
Utility: Carolina Power & Light Company

15 PREPARED BY:
R. W. McDonald, System Heating & Cooling Engineer, Carolina Power & Light Company.

16 VERIFIED BY:
Edgar C. Jones

A. G. Odell, Jr., FAIA
Edgar C. Jones, P.E.

FIGURE 1 EHA CASE STUDIES (CON'T)

TABLE 4

REGRESSIONS OF KWH PER SQUARE FOOT ON HEATING (β_H) AND COOLING (β_C) DEGREE DAYS - EHA DATA

CATEGORY	Monthly Data					Annual Data				
	R^2	α	β_H	β_C	n	R^2	α	β_H	β_C	n
OFFICES	.09	1.86	.00115	.00086	456	.02	3.75	.00332	.00654	38
COMMERCIAL	.04	1.90	.00140	.0026	583	.06	32.04	.00417	-.00123	49
HOSPITALS	.11	2.21	.00244	.00246	108	.08	-10.98	.00815	.01020	9
CULTURAL	.43	.938	.00185	.00059	119	.02	27.11	-.00196	-.00071	10
SCHOOLS	.63	.594	.00165	.00047	581	.02	14.697	.00027	-.00019	49
HOTELS	.37	1.03	.00185	.00238	190	.13	-5.77	.00437	.00744	16
CHURCHES	.14	.346	.00293	.00376	179	.19	-28.44	.00740	.01552	16
LOW RISE	.32	476.8	1.292	1.108	168	.18	-617.8	2.26158	2.83682	14
HIGH RISE	.51	493.92	1.428	3.017	96	.72	-1024.5	7.74855	2.19859	8